NASA CONTRACTOR REPORT

NASA CR-2746

NASA CR-2746

USER EVALUATION OF RIDE TECHNOLOGY RESEARCH

J. R. McKenzie and S. H. Brumaghim

Prepared by
THE BOEING COMPANY, WICHITA DIVISION
Wichita, Kans. 67210
for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1976

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-2746		

4. Title and Subtitle	5. Report Date
USER EVALUATION OF RIDE TECHNOLOGY RESEARCH	November 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
J. R. McKenzie S. H. Brumaghim	D3-11015-1
9. Performing Organization Name and Address	10. Work Unit No.
The Boeing Company, Wichita Division Wichita, KS 67210	513-50-50-01
	11. Contract or Grant No.
	NAS1-13908
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Contractor Report - Final
NASA Langley Research Center Hampton, VA 23690	14. Sponsoring Agency Code

15. Supplementary Notes

Final Report
NASA Technical Monitor: W. Elliott Schoonover, Jr.
NASA Langley Research Center

16. Abstract

An assessment is made of the existing ride technology data base through personal interviews and questionnaire surveys of key ride technology users. The 23 organizations queried represent government, carrier, and manufacturing interests in air, marine, rail, and surface transportation systems. Results are presented which indicate a strong need for common terminology and data analysis/reporting techniques. The various types of ride criteria currently in use are discussed, particularly in terms of their respective data-base requirements. A plan of action is proposed for fulfilling the ride technology needs identified by this study.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Ride Comfort Ride Technology Ride Criteria Aircraft Ride Rail Vehicle Ride Surface Vehicle Ride Marine Vehicle Ride	Unclassified - Unlimited Subject Category 53

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	61	$4.25

* For sale by the National Technical Information Service, Springfield, Virginia 22161

Page
Intentionally
Left Blank

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

USER EVALUATION OF RIDE TECHNOLOGY RESEARCH

By J. R. McKenzie and S. H. Brumaghim
The Boeing Company, Wichita Division

SUMMARY

The purpose of this study was to identify areas of need in the existing ride technology data base from the viewpoint of user organizations. Specific objectives were to identify ride problems which currently occur or can be anticipated as likely to occur in the next generation of public transportation vehicles, to review the adequacy of the current ride technology data base for addressing problems identified and provide indepth recommendations concerning forms of presenting technology results most appropriate for user organizations. The ride technology data base of interest was that dealing with passenger response to the ride of commercial vehicles. It is hoped that the results reported will stimulate interest in the problems associated with providing clearly defined usable ride quality technology data for all transportation modes.

Needs of ride technology users were assessed primarily by means of personal interviews and questionnaires. A total of 23 organizations that play a key role as ride technology users contributed information to this effort. These organizations represented governmental, carrier, and manufacturing interests in air, rail, surface and marine public transportation systems.

Results indicate that a common basis of terminology is needed for meaningful discussion of ride technology. The different types of criteria in use are discussed and the user needs for improvements in the ride technology data base are presented. Needs in the four transportation modes of air, rail, surface and marine were sufficiently alike that a composite was developed.

Finally, a plan of action is proposed by which the user ride technology needs identified by this study could be fulfilled.

INTRODUCTION

The quality of vehicle ride can be a significant factor in achieving passenger acceptance and use of various modes of public transportation. Technology pertaining to the subjective aspects of ride quality is therefore needed which is appropriate for designing and operating vehicles and for helping to evaluate the suitability of existing or planned transport vehicle systems. During the past few years, NASA has initiated a significant effort in this technology in the form of in-house and university grant activities to gain a better understanding of ride quality factors and to build a technology base adequate for supporting design of viable air transport vehicle

systems. This effort has resulted in generation of considerable information pertinent to all modes of commercial mass transit vehicles.

Ride technology has become important in the design of public transportation vehicles due to the influence of several factors. The general increase in operational speed poses a potential ride problem to the designer since, for a fixed environment, the vehicle vertical and lateral acceleration response is approximately proportional to speed. Ride criteria in use today are generally derived from a random or discrete acceleration data base and, in certain applications, only qualitative criteria are available. The user is often faced with applying these types of criteria in vehicle designs because an adequate ride technology base is not available or because existing data are not presented in usable formats.

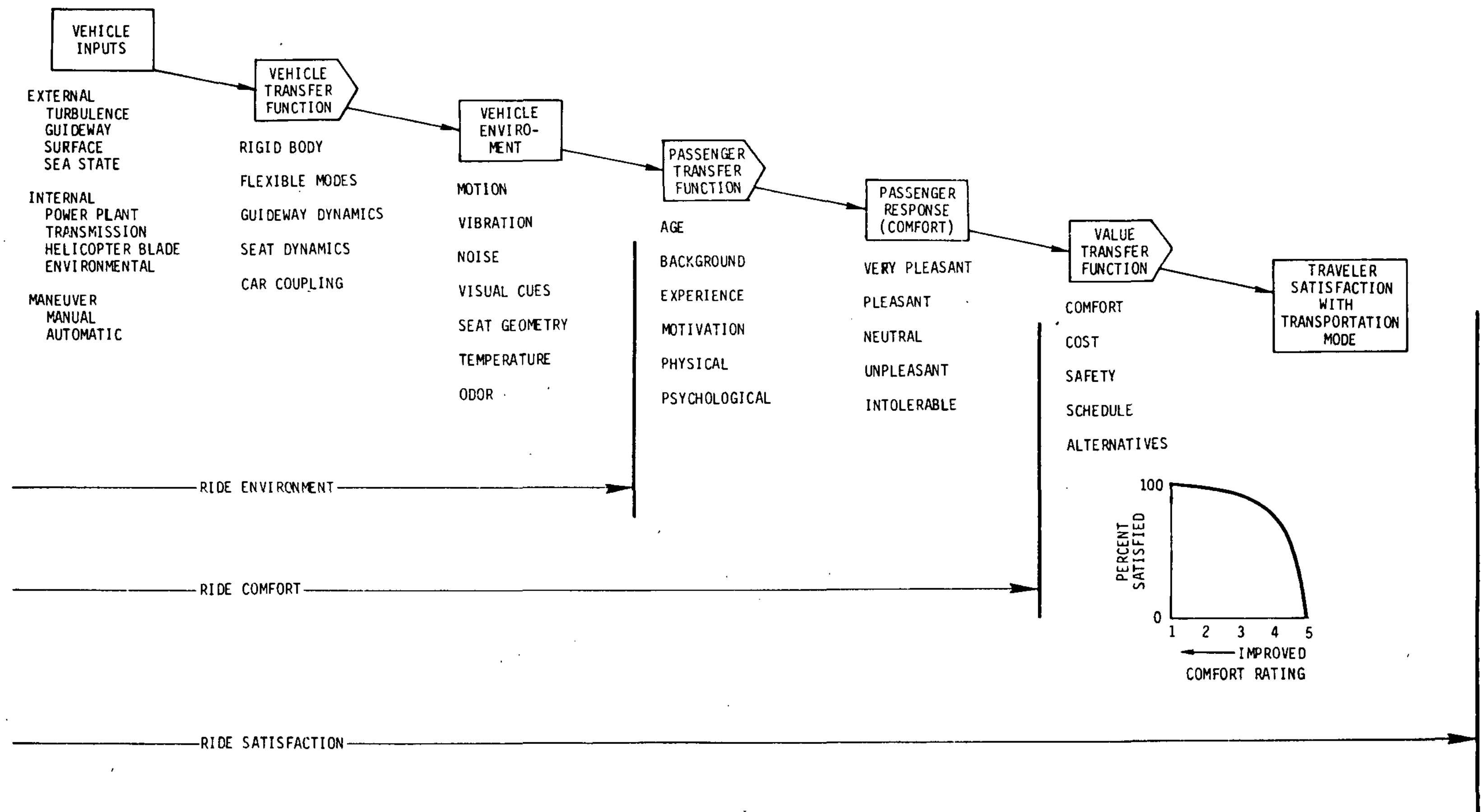
As the demand on user organizations for maintaining acceptable ride increases, there is a need for these organizations to become more directly involved in influencing the direction of ride technology research. The purpose of this study was to identify areas of need in the existing ride technology data base from the viewpoint of user organizations.

Study Definitions

To provide a proper climate for understanding and interpreting results, definitions of key words and phrases used in this report are presented below.

Ride technology is defined as that body of knowledge which provides performance data for the development of vehicle or system ride criteria. Ride technology elements illustrated in Figure 1 encompass vehicle inputs, transfer functions and environment as well as passenger transfer functions, response and satisfaction. Traditionally, the term "ride technology" or "ride environment" has referred to vehicle motions such as acceleration response to inputs from equipment or maneuvers, or inputs from atmospheric turbulence or guideway roughness. This definition is extended in Figure 1 to include the effects of motion and nonmotion variables. Effects of these inputs on the passenger yield an evaluation of ride in terms of comfort. Such evaluation is influenced by many passenger factors including age, background, ride experience, motivation, physical and psychological condition. Because of this, the broad view of passenger acceptance requires consideration of multiple aspects.

Figure 1 is completed by the addition of a passenger ride satisfaction or value transfer function. This transfer function is based on the passenger's expressed willingness to experience a similar ride again. While differences exist among passengers in ride satisfaction for a given ride environment, surveys of many passengers have established that a definable statistical relationship exists between the percentage of passengers satisfied and the mean ride comfort rating. Subjective response may thus be expressed as a curve of percent satisfied versus mean comfort rating, as shown in the figure. Other factors influencing passenger satisfaction with ride such as fares, convenience, etc., were not addressed in this study.



RIDE TECHNOLOGY ELEMENTS
FIGURE 1

Ride criteria is defined as the performance standards for system design and development generated by the user. The interrelationship of technology and criteria implies that a lack or weakness of criteria is a result of an insufficient technology data base and that there is a need for additional research.

Users whose work is associated with transportation vehicles and systems relate to ride technology and criteria in two distinctly different ways. In the first case, users may be governmental agencies or private companies responsible for procuring, operating or maintaining a transportation system or a private company developing a vehicle which it hopes to sell to other companies or to the government. In this case the procurement organizations and company technology groups need an adequate technology base to develop criteria for a system specification or for an internal product development program. In the second case, a user, such as a manufacturer responding to a customer's requirements, is concerned with satisfying the specified criteria.

Current User View of Ride Technology

The individual users' view of ride technology focuses on the criteria he has available or can foresee developing from the existing data base. Ride criteria in use for existing transportation modes deal primarily with vibration effects, although in most cases secondary attention is paid to other amenities such as seating, temperature, humidity, noise and decor. The user is sometimes faced with applying inadequate criteria or adapting to his purposes criteria formulated for other vehicles. He has encountered this situation because sufficient technology has not been developed or because existing data have not been transformed into a design format useful to him. Since discussions with ride technology users generally center on adequacy of ride criteria, basic types of criteria currently employed are identified to help with interpreting the following discussions of users' views.

Three basic types of ride criteria are in use today in the transportation field. The first type of ride criteria is designated the "As Good As" or AGA criteria. These criteria are usually more related to passenger response than to vehicle response although generally there is some attempt to characterize acceptability in terms of acceleration versus frequency or as rms acceleration for a given input. For instance, a potential customer may require that a new vehicle shall ride "as good as" vehicles with which he has had previous experience and confidence of good passenger acceptance. This method has occasionally been taken a step farther by requiring that the new vehicle exhibit accelerations "less than" those encountered with some previous vehicle.

The AGA ride criteria have inherent limitations. For instance, specifications based on AGA criteria provide no basis for cost/benefit trades. Also, in order to show compliance, the ride quality of the vehicle being used as the goal must be determined and then an acceptable method must be devised to demonstrate compliance. In some industries, criteria such as

these have been the traditional means of stating desired ride quality and the method has worked well within a manufacturing company that has previous experience to rely upon. A major difficulty with this approach occurs when a new type or family of vehicles is to be developed.

The second type of criteria is specifically based on results of experiments performed with subjects placed in a pseudo-real passenger environment using moving base simulators. These criteria are usually expressed as limits on some expression of vehicle acceleration versus frequency.

Most experiments of the type generating motion response data have used a small number of subjects with professional or semi-professional backgrounds. Habitability variables are most often fixed and vibrational inputs including noise are varied to observe effects. Also, the vibrational inputs representing vehicle motion are often of a single frequency, single axis nature. Another significant difficulty is that testing is accomplished using a wide variety of rating techniques, such as open ended scales, undefined descriptors, magnitude estimation, etc. Descriptive adjectives alone vary widely in interpretation from person to person. Criteria derived from studies of this type often do not agree in interpretations of acceptable limits of acceleration. Some attempts have been made to resolve these differences, but agreement on criteria specification among transportation modes is still not universal.

The third type of criteria is expressed as an allowed vehicle response for a specified input. This type requires the most technological sophistication of the three because accurate transfer functions of vehicles and seats as well as definitions of vehicle disturbing inputs are required.

It should be pointed out that a passenger's ride response will probably be influenced by his expectations rather than on an absolute basis. This means that an acceptable ride for a train where sway or lateral acceleration may be expected may not be an acceptable ride for an airplane. When different modes of transportation are considered, there may be variable requirements for acceptable levels of acceleration. This argues against the use of a single standard for all types of passenger vehicles. From another point of view, such a universal application of criteria could cause additional and unwarranted cost of design and manufacture if requirements leading to overdesign were established.

STUDY APPROACH

To identify users' ride technology needs, a survey of industry, government and university sources involved in the use of ride technology was conducted in the four modes of the transportation industry, which are:

1) Air
2) Rail
3) Surface (other than rail)
4) Marine

An approach was formulated to allow timely and thorough interrogation of information sources to achieve the objectives of this study. Four methods employed to obtain information were:

1) Personal interviews
2) Questionnaire interviews
3) Participation in the workshop "Needs of the Transportation Community - Present and Near Future", held in conjunction with the 1975 NASA/DOT sponsored Ride Quality Symposium at Williamsburg, Virginia
4) Overview of existing literature.

Personal interviews of key ride technology users were conducted and the results presented in Reference 1 were derived from these interviews. These interviews were augmented by responses to questionnaires which were distributed to ride quality technology users. Questionnaires were intended to expand the information base developed from the personal interviews in such a way as to promote uniformity of analysis. Some preliminary results from this portion of the study were presented in Reference 2. Four different questionnaires were developed for this study and nine of each type were distributed. Each questionnaire was developed to obtain specialized information from persons in one of the four transportation modes: air, rail, surface and marine. Additionally, the broad spectrum of interests in air transportation required a further breakdown into subdivisions of long haul, short haul and helicopters, so that this area was covered by more than one questionnaire type. A number of questions were common to all questionnaires to provide a basis for comparison of results across the four transportation modes. Results are based on a return of 17 of the 36 questionnaires (47 percent). A representative questionnaire is presented in Appendix A.

The quantity of information sources providing interview and questionnaire results is categorized in Table 1. As shown, results are based on interviews of 13 persons representing organizations making use of ride technology and on 17 questionnaire returns, a total sample representing 23 different organizations.

TABLE 1

RIDE TECHNOLOGY USER CONTACTS

Vehicle Classification	Number of Personal Interviews	Number of Questionnaires	Number of Organizations
Air	4	8	10
Rail	3	6	6
Surface	5	2	6
Marine	1	1	1
TOTAL	13	17	23

The organizations that participated in this survey are listed in Table 2 by transportation mode. Participation by interview or questionnaire is indicated. In the air transportation mode, the role of participants included short and long haul carriers, as well as light airplane, large airplane, and helicopter manufacturers. In the rail transportation mode, roles included light and heavy rail car manufacturers, heavy rail car operators, and consultants in light rail and rapid transit. Personal rapid transit and transit bus manufacturers, as well as consultants and investigators of ride technology for surface transportation modes participated. One manufacturer of marine transportation systems participated in the survey of the marine transportation mode.

An understanding of the ride technology perspective of each of the 23 agencies, universities and companies contributing to this critique of the ride technology data base is provided as background for interpreting results. The perspective of each organization is influenced by transportation mode, class of vehicle represented within this mode, and type of product (whether operator, manufacturer or consultant).

Public air transportation may be divided into three basic categories: trunk lines (long haul), feeder lines, and commuter lines (short haul). Organizations represented in the survey are divided as follows: long haul, Trans World Airlines (Operator) and Boeing Commercial Airplane Co., Douglas Aircraft Co. and Lockheed Georgia (manufacturers); feeder lines, AeroMech and Piedmont Aviation (Operators), University of Virginia (research consultant), and Cessna Aircraft (manufacturer); and commuter, Boeing Vertol Co. and Sikorsky (helicopter manufacturers). There is overlap in this classification, primarily between long haul airplane manufacturers and feeder lines in that smaller aircraft manufactured (for example, 737 and DC-9) are used in feeder airlines.

Emphasis in the long haul category is on provision of near "living room" ride comfort. Airplane design and flight domain have resulted in the ride of the long haul jet becoming the standard of acceptability for vehicles of other transportation mode classifications. However, aircraft of new design and operating in possibly different environments (speed, altitude) are expected to meet these same criteria.

The commuter and feeder lines encounter the more significant ride quality problems because they generally operate at lower altitudes where turbulence is more likely to be encountered. This is also true with small, low wing loading aircraft which are more responsive to turbulence than the large jets. In addition, their frequency of takeoff and landing and the accompanying degree of maneuvering motion is greater. Rides are of shorter average duration, however. The chief advantage enjoyed over competing modes of transportation such as rail, bus and private car is that of speed, so that scheduling is of great importance. The higher fare for airplane travel on feeder lines must be justified by overall convenience and reduced time of the trip.

The helicopter environment and operating regime is unique among the air transportation mode classifications. Primary advantages of helicopter travel are reduced trip time through higher speeds and avoidance of ground traffic

TABLE 2

ORGANIZATIONS PARTICIPATING IN SURVEY

Transportation Mode	Organization	Transportation Role	Inter-view	Question-naire
Air	AeroMech, Inc.	Short Haul Carrier		X
	Boeing Commercial Airplane Co.	Large Airplane Manufacturer	X	
	Boeing Vertol Co.	Helicopter Manufacturer	X	X
	Cessna Aircraft	Light Airplane Manufacturer		X
	Douglas Aircraft Co.	Large Airplane Manufacturer		X
	Lockheed Georgia	Large Airplane Manufacturer		X
	Piedmont Aviation, Inc.	Short Haul Carrier	X	X
	Sikorsky Aircraft	Helicopter Manufacturer		X
	Trans World Airlines	Long Haul Carrier		X
	University of Virginia	Short Haul (Consultant)	X	
Rail	AiResearch Mfg. Co.	Light Rail Car Manufacturer		X
	Boeing Vertol Co.	Light Rail Car Manufacturer	X	X
	The Budd Company	Heavy Rail Car Manufacturer		X
	National Railroad Passenger Corp.	Heavy Rail Car Operator (Government)	X	X
	PBQ&D, Inc.	Bay Area Rapid Transit Consultant		X
	US DOT/Trans. Research Center	Light Rail Consultant (Government)	X	X
Surface	Boeing Aerospace Co.	Personal Rapid Transit	X	
	Booz-Allen Applied Research	TRANSBUS Consultant		X
	GMC Truck and Coach Division	Bus Manufacturer	X	
	University of Texas	Automobile (Consultant)	X	X
	Urban Mass Transit Admin.	TRANSBUS	X	
	Vought Systems Division	Personal Rapid Transit Manfacturer	X	
Marine	Boeing Marine Systems	Hydrofoil Manufacturer	X	X

and in accessibility to areas reached over water (such as off-shore drilling sites). Close proximity of the passenger cabin to the engines makes noise and vibration a greater potential problem than for fixed wing aircraft. There is considerable effort apparent to maintain acceptable ride quality over the short duration of flight. Results of this effort are apparent in helicopters of newer design and in future generation models.

The rail industry appears to divide naturally into three classes based on weight, size and number of cars per train. Light rail refers to street-cars and one or two car rapid transit trains operating at moderate speeds on elevated, grade level or subway type track. A middle ground is occupied by the regular subway trains such as used in New York that are larger, heavier, and operate in multicar trains. The third is the heavier intercity type passenger train.

Light rail interests were represented in this study by the U.S. DOT/ Transportation Research Center and PBQ&D, Inc., (consultants) and by Boeing Vertol Co. and AiResearch Manufacturing Co. (manufacturers). Design interest in this class of vehicles is relatively new. Design elements of greatest concern appear to be vibration (both average and peak values), noise, and guideway specifications.

Heavy rail representatives were the National Railroad Passenger Corp., AMTRAK (operator) and the Budd Co. (manufacturer). Historically, there has been little interest in passenger ride quality (except perhaps in accommoda-tions) in this area although this perspective is changing. The advent of the high speed (over 100 miles an hour) train such as the Metroliner has increased interest in ride quality. Track maintenance costs to enable achievement of design speeds, especially over track shared with freight, has made determination of an optimum trade between passenger comfort and track design specifications a critical factor.

The surface transportation mode encompasses the most varied classes of vehicles: Personal Rapid Transit, bus (both urban and intercity) and the passenger automobile. The first was represented by Boeing Aerospace Co. and Vought Systems Division (manufacturers). Personal rapid transit vehicles carry few cars over fairly short distances (such as a university campus at Morgantown, Kentucky, and the Air Trans at Dallas-Fort Worth airport). Pri-mary concern in ride quality is avoidance of unacceptable peaks of vibration and undue sway . Ride during turns and junction crossings is of great con-cern. Again, surface smoothness specifications are critical as they have a large impact on total system cost.

Three organizations involved in bus transportation provided inputs to this user evaluation of ride technology research: the Urban Mass Transit Administration (program director), the GMC Truck and Coach Division (manu-facturer) and Booz-Allen Applied Research (consultant). Environmental features of greatest interest as they affect passenger ride quality are typical vehicle vibration, temperature and air flow. Seating factors are particularly critical over trips of long duration.

Marine-hydrofoil trips of short duration and high speed are most critical (capability of hydrofoil to overtake other marine vessels appears exciting to passengers). Probably, ride is of greatest importance in vehicle design here than in any other transportation mode.

A workshop, entitled "Needs of the Transportation Community - Present and Near Future", was conducted following the NASA/DOT sponsored Ride Quality Symposium at Williamsburg, Virginia, in August 1975. This workshop, which was one of four addressing the overall ride situation, provided another opportunity to identify needs for further development of the ride technology data base and selected results were used in developing the findings of this study. Areas addressed in this workshop related to definition of the importance of ride technology in marketing strategies and identification of needs for further ride technology development. Also, ride criteria forms were discussed and a timetable for required improvements to the ride technology data base was outlined. A list of the Group 2 workshop participants and their affiliations is provided in Table 3.

TABLE 3

WORKSHOP PARTICIPANTS

Chairman:	D. William Conner	NASA Langley Research Center
Cochairman:	Richard L. Scharr	US DOT/Federal Railroad Administration
	George Anagnostopoulos	US DOT/Transportation Systems Center
	Stanley H. Brumaghim	Boeing-Wichita
	Frank Condos	TRW
	Boyd Cryer	General Motors Truck & Coach Div.
	John J. Fearnsides	US DOT/Office of Secretary
	Stanley E. Hindman	US DOT/Urban Mass Transportation Administration
	R. H. McGhee	Virginia Highway and Transportation Research Council
	George Onego	Bell Aerospace Corp.
	Robin K. Ransone	University of Virginia
	Paul R. Spencer	US DOT/Urban Mass Transportation Administration
	Allan Stave	Sikorsky Aircraft
	Avril Brenig	Acoustical Society of America
	In addition, Peter J. Mantle of Boeing Naval Systems Div. provided written inputs and an oral presentation	

Persons responsible for working with ride technology need an adequate data base to support this activity. The existing data base was given a cursory review which is presented in the study findings. Elements of the ride environment addressed are temperature, humidity, air flow, barometric pressure, leg room, seat width, noise and vibration.

STUDY FINDINGS

Study findings based on the questionnaires, personal interviews, the NASA/DOT workshop, and a review of the existing data base are presented in this section for the four transportation modes. Details of questionnaire data are presented in Appendix B and additional data from the workshop on user needs are presented in Appendix C.

Air Transportation Mode

Vehicle motion/vibration was considered the prime determinant of passenger ride quality in the air transportation mode although definition of ride quality most often included other factors as well. Noise, ventilation, temperature and seating characteristics (width, leg room and density) were also heavily weighted as factors affecting passenger ride acceptance.

There was a general difference between airlines and manufacturers in the role ascribed to ride in marketing of their services or product. This difference is a natural one: airlines are responsible for vehicle operation while the manufacturer is responsible for vehicle design. Initial cost and return on investment are the two most important factors affecting design of commercial aircraft from the airlines' point of view. A passenger must have a ride that will cause him to accept that aircraft for future flights but, beyond that, the benefit from increasing costs to make the passenger more comfortable is difficult to ascertain. Normally if the ride is adequate in competition with similar services, costs associated with ride improvement will not be accepted by the airline operator. Direct competition is most often in terms of schedules/trip convenience and fares.

Aircraft manufacturers indicated that projected passenger ride is an important design factor although ranked behind airplane performance variables. Integration of design for adequate ride with aircraft design development was most often expressed as a desired ideal situation. Consistent with the airline operators' viewpoint, however, provisions for improved ride must be shown to be cost effective.

Air transportation is the clearest example of the use of AGA ride criteria. Typically, the ride technology data base is derived from past experience to determine what produces favorable passenger response to ride. The aircraft manufacturer then designs to the dictates of this experience. Other information sources (industrial and governmental standards in order of priority) are used depending on the environmental design factor of interest, but experience was most frequently cited as the basis for passenger environment design decisions.

Consideration of the response to gusts in the preliminary design stage of an airplane illustrates an application of AGA criteria to airplane design. Vertical gust acceleration response sensitivity is evaluated in terms of its rigid body change in lift coefficient due to variation of angle of attack,

$C_{L\alpha}$, or wing loading, lift per unit of wing area. Results of a typical survey are shown in Figure 2. Here, vertical accelerations of several aircraft classes are characterized by their change in lift coefficient due to variation of angle of attack and compared to a baseline which is known to have good passenger ride response.

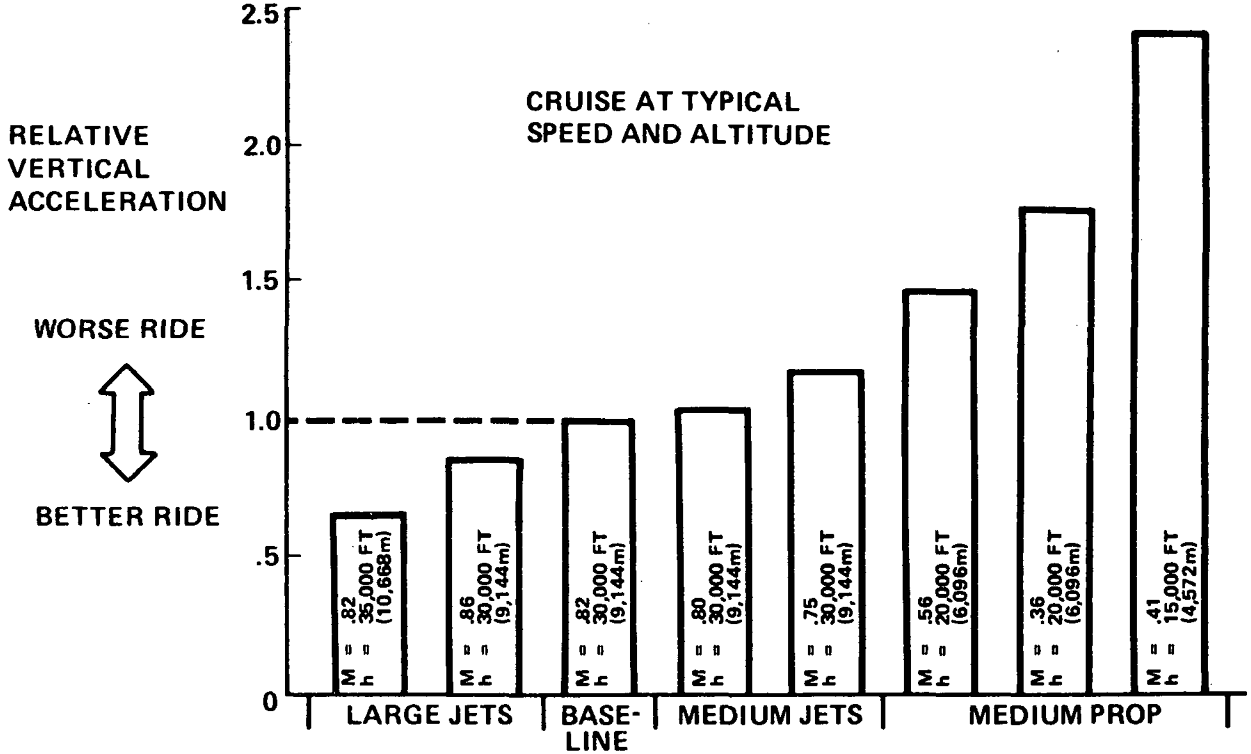
The situation is not as clear in the design of larger more flexible airframes where structural mode dynamics may have a significant role in passenger ride acceptance. Again the AGA criteria are used but a lack of definitive passenger subjective reaction models may lead to problems. The design goal of a recent large flexible airplane in the area of dynamic turbulence response was to be "as good as" a previous acceptable design. During the preliminary design stage it was known that aft body lateral acceleration response to turbulence was slightly greater than that exhibited by the baseline, but a review of passenger subjective response data and consideration of other factors resulted in a decision not to attempt a reduction. Subsequent service operations have revealed adverse passenger response to aft body lateral ride in certain situations and an active control system has been designed for the airplane to alleviate this situation.

When the manufacturer begins the design of a new generation of aircraft not similar to previous designs, he is obliged to consider the ride quality situation in greater depth. For instance, during the conceptual design phase of the American Supersonic Transport, Boeing-Wichita conducted a broad range of studies to determine human reactions to vibrations ranging in frequency from 0.10 to 7.0 Hertz, as reported in Reference 3. These studies were undertaken because the slender, flexible fuselage of the design exhibited lower frequency larger amplitude response to turbulence than had previously been the case with conventional aircraft. This additional study was deemed necessary since passenger reactions to accelerations due to both turbulence and runway inputs were not clearly defined.

The major deficiency in use of AGA-derived ride technology noted above is that this form provides only limited information about acceptable design limits. Insufficient variation in values of environmental design factors and their interactions exists for support of design trades. This problem is highlighted when design of a new generation of aircraft is considered. A further shortcoming is that no family of curves is available for portraying percent of passengers satisfied versus variations in ride environment. Hence cost/benefit trades which are essential for considering design modifications to improve passenger ride but add to initial cost cannot be made with sufficient confidence.

Not-to-exceed criteria were also cited as used, again primarily for specifications of acceptable levels of aircraft vibration. The most common format for these was plots of rms g acceleration versus frequency. A current weakness of criteria in this format was identified as the lack of data relating percent of passengers finding the ride acceptable over varying levels of vibration.

In assessing adequacy of ride technology in specific areas, questionnaire respondents felt in general that data supporting specifications of



RELATIVE VERTICAL ACCELERATION
FIGURE 2

acceptable levels of noise, temperature, ventilation rate, seat contour and leg room were adequate. It was found that standards for temperature, humidity, lighting, ventilation and basic seating factors were normally contained in airline operators' specifications or in FAA egress regulations.

Specific needs for improvement of the ride technology data base relating to aircraft design were, in order of number of times cited: data relating passenger comfort to aircraft vibration, to angular axes of motion, to more complex motion environments (multiple frequency and multiple axis) to combinations of vibration and other environmental factors (such as noise and temperature), and to duration of ride. Needs for ride technology improvement mentioned once were: better data linking passenger response to low frequency (<1.0 Hertz) motions and to conditions associated with varying flight segments (takeoff, cruise and landing, for examples).

The lack of standardization for interior noise measurement techniques and of adequate data correlating subjective response to noise levels was cited as a current shortcoming. Assessment of the adequacy of noise standards therefore appeared mixed.

There was general agreement concerning the most useful formats for ride technology data. Design standards should contain families of curves relating percent of passengers accepting the ride to varying conditions of the ride, should be objective, and should be simple and easily understood by non-engineers.

Helicopters present some unique facets of some problems previously discussed. Noise and acceleration impulses due to blade passages and maneuvers to which the passengers are unaccustomed are the primary adverse ride quality factors. Interior noise levels are generally required to be similar to existing conventional jet aircraft. Each noise source has its characteristic frequency, with engine noise having the highest and least bothersome. Noise criteria are based on hearing loss, fatigue and on speech or communication requirements and are measured in several ways as shown in Reference 4. One serious deficiency in noise measurement is the inability to measure low frequency impulsive noise accurately using current techniques. The methods and units of noise measurement need to be standardized so that existing criteria can be evaluated.

Participants in the 1975 Group 2 Workshop, Needs of the Transportation Community - Present and near Future, detected the need for improvements in the ride technology data base in time to influence design of the Long Haul Helicopter (1976+), the Fuel Conservative CTOL (1977-1985), and the Powered Lift STOL (1980-1985).

Rail Transportation Mode

Vehicle ride quality was most often defined for the rail transportation mode as motion/vibration characteristics of the vehicle, although other design factors such as temperature, humidity and noise were frequently included in the definition as well. Noise, temperature, motion and ventilation were

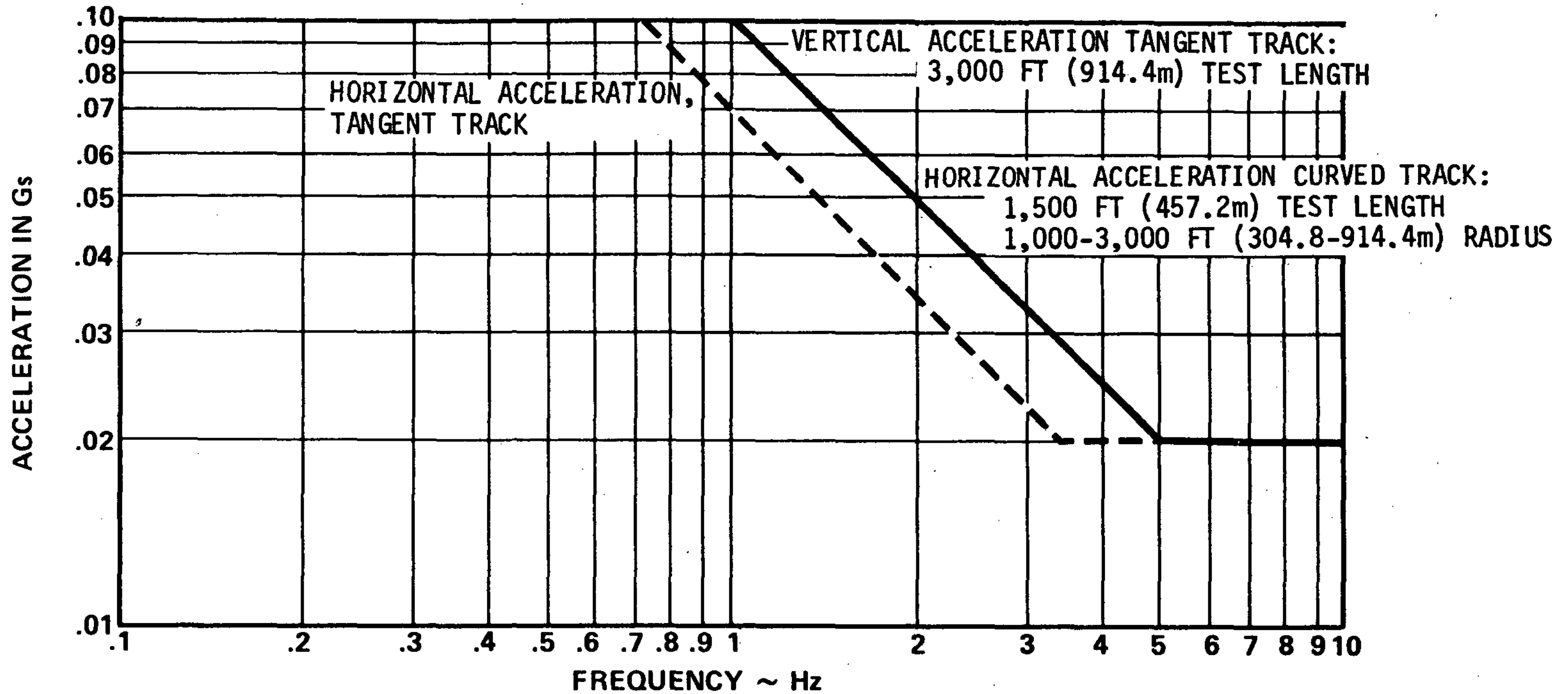
rated in that order as environmental features most affecting passenger acceptance of ride. Persons responsible for the design or operation of light rail vehicles indicated that requirements for an acceptable ride environment should be an important and integral part of the design process, but these requirements were generally ranked in importance behind costs and trip convenience. Ride quality was typically considered to have low priority in the heavy rail transportation segment. This low priority was apparently historical, however with growing emphasis on ride quality evident.

Design, construction and maintenance of tracks was emphasized as an important determinant of passenger ride quality, in addition to design of the vehicle itself.

In rail transport vehicle procurements, both the specific criteria (usually accelerations) and the AGA criteria are used. For instance, the San Francisco Bay Area Rapid Transit (BART) system specifications incorporated specific criteria based on measured accelerations as shown in Figure 3. On the other hand, the AGA criteria used in the specification for new Chicago transit cars stated that ride quality should be equal to or better than that of certain serial number cars already in service as determined by measuring vertical, lateral and longitudinal accelerations. Competitors for this contract had to determine how to measure the ride of the existing cars and then how to compare the ride of their proposed vehicle to show compliance. One complicating factor was that of track inputs. In order to keep inputs regulated, a track with known dynamic characteristics or a particular section of track must be specified. Power spectral density (PSD) must be specified and then, when compliance is to be demonstrated, a track with similar PSD must be used. If track dynamics were specified along with required accelerations, the manufacturer could analytically determine the adequacy of ride in his vehicle with respect to the criteria.

In the ride quality specifications for intercity railroad cars the National Railroad Passenger Corporation (AMTRAK) has taken a more sophisticated approach. This approach consists of specifying a particular track PSD and requiring that the resultant vehicle accelerations meet a certain rms level on one type car and, on another car, that measured acceleration PSD's of the new vehicle and an existing vehicle be analytically transformed to a perceived comfort level for comparison. A data base is being developed from actual measurements of track PSD, vehicle accelerations and passenger subjective reactions using experienced "raters".

Persons involved in the rail transportation mode also assessed adequacy of current ride technology applicable as design guidelines for features in the vehicle environment. Standards setting limits or ranges of comfort for noise, temperature, ventilation, humidity and seating density were judged adequate. Judged inadequate in general were current design guidelines for motion/vibration, external view and seat contour. The lack of quantified subjective response data was apparent. Industrial standards were cited as the most often used source of design guidelines, with experience and government standards following in that order.



BAY AREA RAPID TRANSIT SYSTEM ACCELERATION GOALS
FIGURE 3

Deficiencies in current specifications for control of track dynamics were also noted. Rail construction specifications are always in terms of allowable static deflections per unit of distance traveled. This type of criteria puts very little restraint on the resultant track dynamics at higher frequencies although the trend from jointed to welded rails has moved primary input frequencies away from those most objectionable to the passenger. The impact of track smoothness criteria on construction costs should be considered in selecting applicable criteria since the cost of building and maintaining a dedicated rail system may be a large percentage of the total cost of the system.

Improvements needed for the ride technology data base related to the rail transportation mode included development of valid subjective response curves describing effects of lateral, angular and multiple axis and multiple frequency motions. Effects of varying ride durations should be determined. Interactions among environmental factors should be quantified and, for urban rail, effects of motions on standing passengers should be considered and procedures for measuring values of features of the ride environment, such as vibration and noise, need to be standardized.

Formats desired for data describing subjective response to vibration in the rail transportation mode were rms and peak g acceleration plots and power spectral density plots. Noise measurement was preferred in terms of dbA. Finally, design guidelines should be in terms of data that are easily obtained and reduced.

Planned projects in the rail transportation mode that would benefit from improved ride technology were the Advanced People Mover (1975+) and the Improved Intercity Train (1978+).

Surface Transportation Mode

Ride quality of surface vehicles (other than rail) was equated with vehicle vibration although other factors have an impact on passenger acceptance of the ride. Features of the ride environment determined to be most critical in affecting passenger response were vibration, noise, temperature, provisions for onboard movement and for entry/exit, and seating density.

The importance of ride requirements in vehicle design varies with type of vehicle. Quality of the ride was estimated to rank behind fare cost and trip convenience in terms of passenger acceptance of that mode of transportation.

In surface transport, as in rail transport, there is a proliferation of ride criteria, as well as possible inappropriate application of these criteria. For instance, acceleration versus frequency criteria have been used to define acceptable ride for some recent rubber tired automatic people-mover systems. There has also been some disagreement about correlation between these criteria and the passenger subjective reaction to the ride actually perceived. The need here is to provide the necessary passen-

ger transfer function so that appropriate criteria may be determined and adjustments made if necessary.

Another important facet of the ride criteria situation is the required interior noise level. The ability to achieve required levels is affected by many factors. For instance, the fact that maintenance requirements may severely impact the noise level illustrates the need to consider the effects of all inputs. Maintenance requirements that dictate ease of cleaning and low susceptibility to vandalism can cause difficulty in achieving required noise levels. The conclusion then is that all factors affecting ride should be considered simultaneously, weights for each input established, and trade studies conducted to define costs.

The AGA criteria are also used in the surface transport mode. One such case is found in the TRANSBUS program sponsored by the Urban Mass Transit Authority, where prototype transit buses were developed to a ride criteria goal of "as good as a 1973 Ford LTD". In order to apply this criterion, quantitative data had to be generated. This involved building a test track with simulated roadway anomalies and evaluating two automobiles of the type specified as well as an urban bus to serve as a baseline. Results are reported in Reference 5. Here again, as in other transportation modes, we find the AGA criteria being used with the result that these criteria must be quantified before they can be applied.

In some cases of commercial manufacture, this quantification step is bypassed by the use of subjective evaluations by experienced raters and management personnel. This approach has apparently proven workable in the past in lieu of quantitative acceleration criteria.

The surface transportation modes face problems similar to those described for the rail transportation modes in the area of guideway surface criteria. Again the usual specification relates to static deflections and very little dynamic modeling information is available to the investigator so that he can realistically predict vehicle response to random inputs. Some work is being done in this area as shown in Reference 6 to try to quantify guideway surface dynamics and produce criteria other than the familiar acceleration criteria. The approach has been to generate a figure of merit based on a particular weighting of vehicle response variables. This approach has been investigated by the British Railways Board and is also being investigated at the University of Texas where an ISO weighted ride index has been developed that exhibits good agreement with passenger subjective reaction to automobile ride. Some results are presented in Reference 7.

An added weakness noted in the available ride technology data base was lack of information for making provisions for onboard movement. Current standards for setting acceptable limits or ranges for noise, temperature, ventilation, seat width, leg room, seat contour and seating density were judged adequate. Industrial standards were the most frequently used source of design information.

Improvements in the following ride technology data base areas are called for: improved vibration standards including passenger subjective

response to mixed periodic and random vibration, transient peaks and combined axis vibration; more information regarding effects of interactions of environmental variables on passenger ride acceptance; and data describing effects of motion on standing passengers. Effects of vehicle environment on passenger task proficiency (reading and writing as examples) and of vehicle inputs on driver comfort need to be quantified.

Currently planned projects in the field of surface transportation which would benefit from these ride technology improvements are the Advanced Transit Bus (1976+) and the High Speed Intercity Bus (1980+).

Marine Transportation Mode

Vehicle ride quality in the marine transportation mode is defined as including all aspects of the environment which influence passenger acceptance of the ride. Onboard services such as food, beverages and entertainment are also seen as important in this respect. Ship motion, noise, temperature and ventilation are features of the environment most critical to passenger comfort. Impact of ride design requirements relative to other factors affecting vehicle design is considerable. Experience has shown that passengers will pay higher fares for short trips on ships for which incidence of motion sickness is significantly lower.

The criterion used for specification of vehicle motion design requirements was expressed as an allowed vehicle response to a specified sea state. This approach is objective and straightforward and compliance is easy to measure. However, accurate knowledge of the ship's dynamic response and of seat transmissibilities is required. A valid correspondence of the specified output to acceptable levels for passenger acceptance is assumed.

The primary deficiency in ride technology for the marine transportation mode is for motions in the frequency range below 1 Hertz. Since this is the frequency range in which motion sickness is predominant, criteria in the range below 1 Hertz are of utmost interest in the design of marine vehicles. Information is lacking on the effects of motion and the effects of duration of the motion. It is possible that different criteria might be required for passengers and crew due to the effects of duration and experience in this low frequency range. A valid approach for integrating passenger reactions over a trip exposure time profile would be useful.

Another related deficiency is the effect of combined axis inputs on the passenger reaction to motions in this frequency range. As in other transportation modes investigated, habitability variables such as temperature, seating, etc., are specified but effects are not assessed to determine impact on ride.

Another weak criteria area is in the specification of a sea model. Models similar to those used to define atmospheric turbulence have been developed to aid in marine vehicle analysis and synthesis, but work in this area is by no means complete or adequate. Once again the passenger subjective reaction needs to be quantified so that the manufacturer can predict passenger reaction to proposed marine vehicle ride. The manufacturer could

then predict the percent of passengers that would be satisfied with ride in a particular customer's operating environment and more easily reach adequate contract agreements. This capability would also allow overdesign to be identified and reduced, thereby reducing costs.

Requirements of a format for ride technology data applicable to marine vehicle ride environment are that they be interpretible by nonengineers and be in a form which can be easily integrated with other vehicle design requirements.

Ride Technology Data Base Overview

Persons involved in work with ride technology need an adequate data base to support this activity. The existing data base is briefly reviewed herein for two purposes. First, the ride technology data base is in considerable flux. User evaluation of ride technology research is generally based on standards or data which have existed for some time. Information concerning the currently evolving data base therefore provides an opportunity to assess whether the direction of this expansion is appropriate for users' needs. Second, it is possible that a primary user need may be for more effective visibility of the current ride technology data base and not necessarily for improvement in the data base itself. This overview provides the reader an opportunity to evaluate, once user needs have been reviewed, whether this is in fact the case.

Elements of the ride environment addressed are temperature, humidity, airflow, barometric pressure, seating factors, noise and vibration. An excellent starting point for persons interested in a more detailed review of the relevant literature is Reference 8, which develops initial environmental criteria for motion, noise, temperature, humidity and pressure. Reference 9 is an excellent source of information concerning status of ride technology research, with emphasis primarily on motion variables and secondarily on noise. Other features of the passenger vehicle ride environment addressed in this report include seating factors, barometric pressure, visual cue effects and temperature (References 10, 11 and 12).

This overview considers only those potential sources of criteria which are published in the general literature or which have been presented at technical meetings covering a specific area of ride quality data. This restriction excludes consideration of criteria based on passenger vehicle manufacturers' or passenger carriers' experience with consumer acceptance of their product, unless these criteria are in published form. Appropriate reference is made to ongoing ride technology-related studies for which interim results have been presented. In general, the ride technology data base is not differentiated in terms of modes of transportation to which it applies. Exceptions are noted as appropriate.

Three components of the vehicle ride environment, temperature, humidity and rate of air flow, are commonly discussed jointly. It appears that there is general agreement among existing handbooks regarding comfortable ranges although there may be minor differences. A comprehensive review of relevant

data is found in References 13, 14 and 15.

Primary concern in the area of barometric pressure has been the rate of change of pressure that is acceptable to air travelers. References 10, 15 and 16 present ranges of barometric pressure which are acceptable to passengers and which are in general agreement with one another.

Space available to the seated commercial passenger for leg room and seat width is an important factor affecting assessment of vehicle ride, particularly if the trip is extended and movement within the vehicle is restricted. Anthropometric data are available in standard design handbooks to establish these space requirements. In addition, References 10 and 17 present guidelines for seat pitch and width acceptable to the passsenger.

The data base from which ride noise criteria may be drawn is more fragmented than for the elements of the ride environment discussed above for a number of reasons. Most of the literature relating subjective reactions of persons to noise levels deals with the problem of community reactions to noise sources such as road or rail traffic and airplane fly-overs. There is also disagreement on the most appropriate scale of noise measurement and the best means of measuring or evaluating the passenger noise environment. There are also problems in reaching a consensus on the level of subjective response that defines an unacceptable noise environment. References 8 and 16 contain relevant discussions of different approaches taken to define noise exposure criterion.

There is a large amount of data available describing the human reaction to motion. References 8 and 18 provide results of literature searches that include most of the relevant reports. Reference 19 contains a record of the considerable vibration research conducted in the United Kingdom.

Most of the literature deals with human response to single frequency, single axis vibration (generally vertical or lateral). The most widely recognized guidelines in this area are the ISO standards of Reference 20, which address human comfort response to vertical, lateral and longitudinal vibration in the frequency range above 1.0 Hertz. Discussion of these guidelines is contained in References 21, 22 and 23.

Perhaps the most rapidly expanding area of ride technology research that has not yet impacted users' views is that involving effect of combined vertical and lateral accelerations on passenger comfort. Results of this work are reported in References 12, 24, 25 and 26.

Relatively less information is available concerning effects of multiple frequency and angular motions on passenger comfort. Exploration of the multiple frequency environment as it affects subjective response is reported in References 27 and 3. Initial studies to relate passenger acceptance of angular motions are reported in References 26 and 28. Reference 29 contains a preliminary psychophysical model relating subjective response to linear and angular axes of motion.

Data describing passenger response to vertical and lateral vibration at

frequencies below 1.0 Hertz were obtained in a research flight test program conducted at NASA-Edwards. These data are reported in Reference 30. Results of a study to link incidence of motion sickness with frequencies and acceleration of vertical motion are reported in Reference 31. Related work on the study of effects of shipboard motion on human response is reported in Reference 32. Equal subjective intensity curves for the frequency region 0.25 to 4.0 Hertz (vertical vibration) are reported in Reference 33. A current proposal to extend ISO curves below 1.0 Hertz down to 0.10 Hertz is reported in Reference 21.

Little research has been conducted to investigate effects of combinations of ride variables on passenger ride comfort. Research reported in Reference 4 indicates that combinations of heat, noise and vibration were judged more stressful than was any component variable alone.

Users' Needs

Results of this study identified similarities in needs of ride technology users in the four public transportation modes. In fact, one list of users' needs has been constructed that will suffice in general for all transportation modes. This list is presented in Table 4.

Of most immediate benefit to users would be greater standardization of conditions on which the ride technology data base is founded. This would lead to development of more appropriate design specifications. A description of problems largely due to insufficient standardization in design of advanced ground transportation is contained in Reference 34.

Standardization needs relate to definition of critical parameters of the ride environment that are relevant for vehicle design, to selection of measurement techniques (including units of measurement) and to identification of data format. Standardization requirements are general across all transportation modes; standardized values may be general across modes or specific to only a given class of vehicles within a transportation mode.

The need for standardization is greatest in the vehicle motion/vibration ride technology data base. For instance, there is the question of applicability of single frequency, single axis inputs in the evaluation of vehicle response to random disturbances. Application of design specifications based on average acceleration criteria to an environment in which transient peaks can be expected is an additional problem. Appropriate frequency bandwidths and duration of samples over which acceleration limits are specified must be standardized. Results of moving base simulator studies may be suspect to the user where potentially meaningful differences between the simulated and operational vehicle environment can be noted. Biases resulting from these differences need to be identified and accounted for. The user is most aware of these limitations as they affect specifications of vehicle ride environment or procedures for demonstrating compliance with these specifications. Development of a data base under conditions compatible with specification requirements, however, is a prerequisite.

TABLE 4
USER NEEDS

USER NEEDS	BENEFITS
STANDARDIZATION OF RIDE TECHNOLOGY DESCRIPTIONS • ACCELERATION – UNITS – EXTEND BELOW 1 Hz – SINGLE FREQUENCY VERSUS RANDOM – COMBINED AXIS EFFECTS – MULTIPLE FREQUENCY EFFECTS – FIGURE OF MERIT • NOISE – UNITS – MEASUREMENT TECHNIQUES – MEASUREMENT LOCATIONS – PASSENGER LOADING • ANALYTICAL REPRESENTATION OF INPUTS	• EASE OF COMMUNICATION BETWEEN CONTRACTING PARTIES • FIRM BASE FOR DEMONSTRATING SPECIFICATION COMPLIANCE • IMPROVED APPLICATION OF ANALYTICAL TECHNIQUES • INCREASED CONFIDENCE IN RESULTS
QUANTIFICATION OF PASSENGER SUBJECTIVE REACTION • CORRELATION WITH MEASURABLE RESPONSE PARAMETERS • DETERMINE COMBINED EFFECTS OF OTHER INPUTS	• ELIMINATION OF POSSIBLE OVERDESIGN • ASSURANCE OF CERTAIN PROBABILITY OF PASSENGER RESPONSE • INCREASED EASE OF MARKETING
DETERMINATION OF IMPROVED RIDE COSTS • CRITERIA WEIGHT • IMPACT ON SYSTEM COST • TRADE STUDIES	• MORE INTELLIGENT APPLICATION OF CRITERIA • MINIMIZED SYSTEM COSTS
ADVANCED SPECIFICATION FOR GUIDEWAY CONSTRUCTION • DYNAMIC AS WELL AS STATIC	• CONTROLLED VEHICLE INPUT

The situation that allows a proliferation of criteria without sufficient guidance for application places an unacceptable burden on the contractor trying to demonstrate specification compliance as well as the customer trying to confirm compliance. If compliance is to be demonstrated analytically, proper mathematical models of vehicle input such as a power spectral density of rail or guideway surface smoothness should be developed for use and standard methods of determining vehicle response should be agreed upon. In addition, standard methods of vehicle response measurement should be defined so that demonstration of specification compliance is adequate.

"As Good As" criteria may or may not have adequate measurement standardization depending in general on whether or not the manufacturer of the newly designed vehicle has also manufactured the comparison vehicle. Use of the AGA criterion form for specification of ride environment of a new vehicle is inherently restricted, however, by ride transfer functions of the comparison vehicle. Standardization on the "limits" criterion format with its more general applications appears preferable. Such a format might be the figure of merit type or the more familiar acceleration versus frequency format. Users' preferences for general characteristics of a format are clearly stated. They should ideally be quantitative, should be based on data easily obtained and processed in a straightforward manner, and should be interpretible by non-engineers.

Standardization does not mean the application of one criterion to all vehicles. In fact, it is quite possible that criteria magnitudes should be adjusted for applicability to different modes and, in some instances, to different vehicles within each mode.

Agreement of standard units and methods of noise measurement is viewed as required by some. Typical noise measurement locations, vehicle configuration and passenger loading should be defined. A majority of questionnaire respondents in the air and rail transportation modes felt that existing noise level criteria were adequate, however.

Passenger subject reaction must be quantified and correlated with an easily measured vehicle response parameter, probably acceleration. This would allow the user to predict passenger response to projected ride environments more precisely. Specific existing data gaps include those relating to effects on passengers of ride duration (all modes), effects of multiple-frequency and multiple-axis vibration (air, rail and surface), effects of angular motions (air, rail and surface), effects of transient peaks (rail, surface and marine), effects of low frequency inputs (air and marine), and effects of noise (air-helicopters). Persons involved in design of intra-urban vehicles (both rail and surface) shared concern for obtaining data correlating response of standing passengers to vehicle ride.

Existing guidelines for temperature, ventilation, humidity and noise were mostly judged adequate; however, a further general users' need indicated for air, rail and surface vehicles was quantification of passenger response to interactions of these factors, primarily with varying levels of motion. The need for data relating passenger reaction to vehicle motion as a function of seat design was also cited.

More valid quantification of passenger subjective reaction to features of the ride environment would enable the user to predict passenger ride response more precisely. Benefits beyond preliminary assurance of specification compliance would include more intelligent marketing and elimination of some overdesign with subsequent lowering of manufacturing cost.

The user must be given a means to establish cost benefit tradeoffs with relation to improved ride. Some vehicles within a transportation mode may need more sophisticated criteria than others depending on the job to be performed, but applying criteria without first determining the impact on system cost may penalize a particular transport mode by escalating initial and/or maintenance costs. The percent of passengers satisfied with the ride versus the cost of providing the ride should be quantified so that the desired cost effectiveness can be determined.

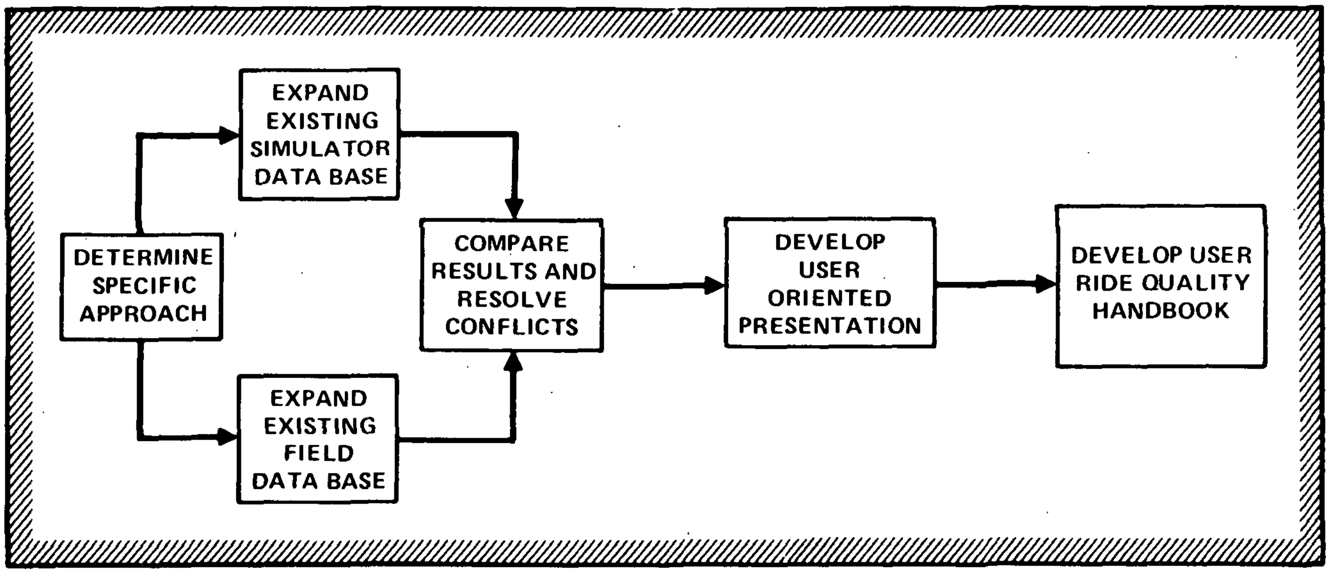
User needs are indicated in the area of guideway specification. This includes both rail and concrete. Advanced construction techniques developed to meet more stringent guideway smoothness specifications would provide more controlled vehicle inputs and would allow a more realistic or consistent analytical description. However, construction and maintenance costs would increase with increased demands for smoothness and resulting requirements for measurement accuracy. This is a formidable problem because any increase in cost per mile of construction will escalate.

The introduction to Reference 6 states that "construction and maintenance requirements must be established in a form compatible with surveying and construction practice so that guideway costs can be accurately estimated and traded off against vehicle suspension sophistication". Various improvements to existing methods of specification should be pursued with the constraint that they must result in requirements compatible with measurement and construction capabilities.

A related user need cited for marine vehicle ride technology is a requirement for improved definition of sea states for areas in which passenger transport is planned. In short, the transportation modes in which there is vehicle contact with a relatively hard supporting medium (rail, pavement and water) require an improved understanding of dependence of passenger comfort on characteristics of the supporting surface. Understandably, as noted earlier, persons involved in vehicle design in these three modes of transportation indicated a need for improved data correlating passenger subjective reaction with transient acceleration peaks.

A concerted and coordinated effort will be required to meet the previously described ride technology needs. It is apparent that cooperation among diverse interests such as government agencies, universities and industry is desirable due to scope of the task and variability of the transportation mode requirements. The following describes a possible approach to bring the varied strength of these diverse interests to bear on the areas of obvious need with some degree of efficiency.

An ideal approach to integrated ride technology development is outlined in Figure 4. The total approach could be coordinated by an organi-



INTEGRATED RIDE TECHNOLOGY
DEVELOPMENT APPROACH
FIGURE 4

zation is as advisory status with responsitility in all transportation modes to evaluate state of the art in ride technology, to identify and prioritize research to be accomplished, and to make provisions for technical interchange of data.

The first requirement would be to identify in detail deficiencies in the ride technology data base for each transportation mode and to recommend detailed approaches by which to eliminate them. The approaches selected might encompass efforts of many individuals or groups and would lead to an expansion of the existing simulator and field data base.

Expansion of this data base should be accomplished through a coordinated program of simulator and field testing. The different strengths of these two approaches could then be exploited for this purpose; there should be sufficient overlap between simulator and field tests to provide a basis for evaluating data biases peculiar to either approach. To the extent possible, laboratory and field data should be correlated and discrepancies resolved. An integration of data from these two sources would then lead to development of a high-confidence ride technology data base.

The next step is to transform results into forms that can be utilized in the transportation mode of interest. This is probably the area that will most heavily influence acceptance and usefulness of results from additional ride technology development. The forms of technology presentation must be straight-forward and applicable and interpretation must be unambiguous.

Much existing data do not clearly state how they are to be applied or how data were gathered. Criteria derived from these data suffer from the same problems and they sometimes suffer from additional problems of determining which variables to measure, where to measure, what tolerances to apply, and how to reduce the data. To solve this problem measurement standardization principles would be established.

Once appropriate forms of presenting ride technology for each transportation mode and methods of use have been developed, they would be incorporated into a Designer's Handbook. This handbook would contain information to allow the vehicle designer to formulate a strategy to evaluate ride technology whether analytically or in the field.

For analytical evaluation, methods of calculating the appropriate ride index would be given along with proper representation of typical inputs to be encountered. For field evaluations, appropriate information related to variables to be measured, location of instrumentation, tolerances, and accepted methods of data reduction would be supplied. This information would be related to a particular transportation mode. Additional details of this proposed approach are provided in Appendix D.

CONCLUDING REMARKS

Results of this study have shown that the ride technology user generally perceives technology weaknesses through the ride criteria that are subsequently developed. Technology weaknesses identified during this study are discussed in detail and appear to be concentrated in four areas. First, ride technology data formats need to be standardized so that standard criteria may be developed. In conjunction with this, units and methods of measurement should be standardized. Passenger subjective reaction to vehicle ride must be quantified so that the user can accurately predict the percent of passengers satisfied. Techniques to improve ride must be assessed so that the user can determine the level of ride he can afford. Finally, advanced techniques for properly specifying and evaluating the effect of distrubance inputs must be developed based on a general method of evaluating passenger satisfaction.

A plan of action was proposed to accomplish these requirements. The proposed action calls for an organized method to coordinate, evaluate, analyze and disseminate information regarding the total ride technology effort for the four transportation modes of air, rail, surface and marine. This effort will require many organizations working in concert and would involve expansion of the existing field and simulator data bases with comparison of results to allow the resolution of conflicts.

Following accomplishment of these tasks, user oriented data and criteria forms may be developed. User orientation of the ride technology data base would allow greater ease of communication among the users with an attendant reduction in operational problems. Information developed should be provided in a designer's handbook which would document accepted techniques for both analytical estimate of passenger satisfaction and field measurements for verification of predicted passenger satisfaction.

A general timetable for needed ride technology improvements was determined, based on results of a workshop of the 1975 Ride Quality Symposium. The timetable indicates that extensive ride technology research needs to be conducted over the next 2-4 year period and beyond.

APPENDIX A

REPRESENTATIVE RIDE TECHNOLOGY QUESTIONNAIRE

Four different questionnaires were developed for this study. Nine of each type were distributed. This appendix contains a representative questionnaire.

RIDE EVALUATION QUESTIONNAIRE

RIDE QUALITY DEFINITION:

Ride Quality (RQ) is defined here as impact on the passenger of all aspects of the carrier vehicle physical environment that affect his acceptance of the ride. Environmental factors falling within this definition would include such things as vibration, temperature, seat configuration, and visual field. Onboard food/beverage service or enroute entertainment are among environmental factors <u>not</u> falling within this definition.

Given this definition of ride quality, please answer the following questions and complete the accompanying checklist.

1. What is your definition of RQ as used in your business?

2. Please describe the RQ criteria formats you use in determining new vehicle requirements.

3. Describe specific areas in which you feel you need improved RQ criteria.

4. What form of criteria do you find most useful?

5. What weight do you give to RQ in your overall marketing strategy?

INSTRUCTION SHEET

RIDE QUALITY CRITERIA EVALUATION QUESTIONNAIRE:

QUESTION NO.	EXPLANATORY REMARKS
2	Examples of RQ criteria format possibilities are: frequency vs. RMS acceleration plots or mean acceleration values for motion; single dimensional (temperature) or two-dimensional (temperature vs humidity) plots; speech interference levels or dbA for noise, etc.
3	A specific area of need might be "seat width" criteria or criteria for "passenger response to vertical vibration from 10-20 Hz".
4	Possibly useful forms of criteria might be: graphs or equations; "do not exceed" limits or descriptions of passenger response in terms of percentiles accepting various levels of intensity; certain units of measurement which you prefer.
5	This question is intended to obtain the status of RQ criteria relative to other vehicle design features considered in development of a vehicle, or in operating that vehicle in a competitive manner.

RIDE CRITERIA EVALUATION CHECKLIST: (TABLE 5)

AREA	EXPLANATORY REMARKS
Importance For Passenger Ride Acceptance	For example, "temperature" would receive a higher numerical rating than "seating density" if you felt passengers were more influenced by temperature than seating density in evaluating vehicle ride quality.
Adequacy of Criteria	Criteria should be judged adequate if you feel comfortable with acceptable <u>and</u> unacceptable ranges set by these criteria. If existing criteria in given areas are judged inadequate, please check the most appropriate box (or boxes) indicating reasons for this inadequacy. Specific ways in which you feel criteria can be improved can be given in response to Question 3 of accompanying questionnaire.
Source of Criteria	Mention of specific sources in the appropriate box would be helpful; i.e., Bioastronautics Data Book under "Other" if this source were used to set acceptable limits for humidity, or AFSC Handbook DH 1-3 under "Gov't. Stnd./Reg." if that were used to set vibration limits.

TABLE 5
REPRESENTATIVE RIDE CRITERIA EVALUATION CHECKLIST

ELEMENT OF PHYSICAL ENVIRONMENT	JUDGED IMPORTANCE FOR PASSENGER RIDE ACCEPTANCE (1)	USE OF CRITERIA			ADEQUACY OF CRITERIA				SOURCE OF CRITERIA			
						NOT ADEQUATE						
		DO NOT APPLY	DO NOT USE	DO USE	ADEQUATE	NONE AVAILABLE	NOT IN USABLE FORM	NOT VALID	INDUSTRY STND.	GOV'T. STND./REG.	COMPANY EXPERIENCE	OTHER (PLEASE SPECIFY)
MOTION – RESPONSE TO ENVIRONMENT												
MOTION – CAUSED BY MANEUVERS												
NOISE												
ODOR												
TEMPERATURE												
VENTILATION RATE												
HUMIDITY												
EXTERNAL VIEW (FROM SEAT)												
PROVISIONS FOR ONBOARD MOVEMENT												
SEAT WIDTH												
LEG ROOM												
SEAT CONTOUR/ CUSHIONING												
SEAT HEAD REST												
SEATING DENSITY												
SAFETY RESTRAINTS												
OTHER (PLEASE SPECIFY)												
OTHER (PLEASE SPECIFY)												

IQ750492-1

(1) RATING SCALE: 1 = NOT IMPORTANT
2 = OF SLIGHT IMPORTANCE
3 = MODERATELY IMPORTANT
4 = QUITE IMPORTANT
5 = VERY IMPORTANT

APPENDIX B

RIDE TECHNOLOGY QUESTIONNAIRE DETAILED RESULTS

Four different questionnaires were developed for this study. Nine of each type were distributed. In general, each questionnaire was developed to obtain specialized information from persons in one of the four transportation modes: air, rail, surface and marine. Additionally, the broad spectrum of interests in air transportation required a further breakdown into subdivisions of long haul, short haul and helicopters, so that this area was covered by more than one questionnaire type. A number of questions were common to the four questionnaires to provide a basis for comparison of results across the four transportation modes. Results are based on return of 17 of the 36 questionnaires (47 percent).

The questionnaire approach was taken to broaden the study survey base beyond that practical for personal interviews and to provide a common set of questions to which respondents replied.

Questionnaires were distributed to persons interviewed as well as to additionally selected ride technology users to provide a common basis for interpretation of results. The 17 (47 percent) questionnaires returned included seven from the thirteen organizations contacted for interviews. Breakdown of questionnaire returns by transport mode was as follows: Marine (1), Surface (2), Light Rail (3), Heavy Rail (3), Short Haul Air, including helicopters (5), and Long Haul Air (3).

Questionnaire results generally confirmed the tentative conclusions reached in the personal interview survey with regard to the users' view of ride technology. General results of the study are presented here along with more detailed observations based on questionnaire data.

Definition of ride quality - The term "ride quality" as used in the questionnaire was defined as the "impact on the passenger of all aspects of the carrier vehicle physical environment that affect his acceptance of the ride". Factors included in this definition were vibration, temperature, seat configuration, visual field, etc.; factors excluded were onboard food/beverage service and enroute entertainment. Respondents were then asked to give their definition of ride quality as used in their work.

Results are presented in Table 6. Vibration was unanimously selected as falling within the respondent's definition of ride factors. Other factors included as relevant for vehicle ride consideration by over 50 percent of the respondents were noise, temperature, humidity and ventilation. Seat design and passenger view were judged by only slightly over one third of respondents as factors impacting vehicle ride. These results do not mean that respondents felt seat design and passenger view were unimportant for passenger comfort, rather they indicate a lack of ability to quantitatively assess such effects. View, for example, was later rated to be "moderately important" for passenger acceptance of vehicle ride. As a final note,

TABLE 6
SURVEY RESPONDENTS' DEFINITION OF RIDE

ENVIRONMENTAL FACTOR	PERCENT RESPONDENTS INCLUDING FACTOR IN RIDE DEFINITION
VIBRATION	100
NOISE	69
TEMPERATURE	62
HUMIDITY	54
VENTILATION	54
SEAT CONFIGURATION	38
VIEW	38

one respondent indicated that passenger assessment of vehicle ride could not be separated realistically from onboard food, beverage and entertainment services.

Ride importance in marketing - Respondents were asked to indicate the weight that ride considerations were given in determining overall strategy for marketing the vehicle or carrier services. Responses indicated that with the exception of the heavy rail transportation mode, ride was a major factor in marketing strategy and should be considered early in development of vehicle design. However, with the exception of marine vehicle design, ride was customarily ranked third or fourth in terms of design priority, with performance and cost factors typically assigned a higher priority. The necessity of meeting competition in terms of vehicle ride was also mentioned as a driving force in establishing priority of ride for vehicle design.

Responses from 15 questionnaires were tabulated to reach the above conclusions. To this number were added three responses made to a similar question asked of participants attending the Users' Needs workshop at the 1975 Ride Quality Symposium. Data obtained from the 18 responses are presented in Table 7.

Exceptions to general results described above were that ride was a most important element affecting design of a marine vehicle and that ride was considered to have typically low priority in the heavy rail transportation mode. This low priority was seen to be historical, however, with a growing emphasis on ride quality evident.

Respondents were asked to judge adequacy of criteria in each of several areas related to vehicle ride and to identify the general source of criteria for each area. Also, an open-ended questionnaire item asked for a listing of areas in which existing ride criteria could be improved significantly. Finally, a five-point numerical rating scale was used to obtain an estimate of the importance of each of several factors in terms of its impact on passenger ride acceptance. Survey results for these items are discussed in the following paragraphs.

Evaluation of existing criteria - Data related to judged adequacy of existing ride criteria and identification of general sources of these criteria are shown in Table 8. There were in general no differences among transportation modes in estimated adequacy of existing criteria. For this reason and since an alternative treatment would have sacrificed interpretibility because of a small sample in each category, results were summarized without regard to transportation mode. Environmental factors for which criteria were judged inadequate by a majority of four or more respondents were motion, maneuvers, view and provisions for onboard movement. Factors for which criteria were judged adequate by most or all respondents were noise, temperature, ventilation rate, humidity, leg room and seating density.

Industry standards and experience were the primary general sources of existing criteria, accounting for 43 percent and 41 percent of responses respectively. Experience was taken to refer to familiarity with passenger reaction to environmental features of existing vehicles and includes the "as good as" criterion. Government standards or guidelines were cited as criteria sources in only 16 percent of the responses.

TABLE 7
RIDE MARKETING IMPORTANCE

GENERAL RESPONSE	NUMBER RESPONDING
RIDE RANKS THIRD OR FOURTH ON PRIORITY LIST	5
RIDE IS A MAJOR FACTOR IN MARKETING STRATEGY	4
RIDE CRITERIA SHOULD BE USED IN INITIAL DESIGN DEVELOPMENT AND EVALUATION	3
VEHICLE RIDE MUST MEET RIDE QUALITY OF COMPETITION	3
RIDE RANKS BELOW FOURTH ON PRIORITY LIST	2
DESIGN EMPHASIS IS ON RIDE	1

TABLE 8
JUDGED ADEQUACY AND SOURCES OF RIDE TECHNOLOGY DESIGN CRITERIA

ENVIRONMENTAL FACTOR	JUDGED ADEQUACY OF CRITERIA		CRITERIA SOURCES		
	ADEQUATE	INADEQUATE	INDUSTRY STANDARD	GOVERNMENT STANDARD	EXPERIENCE
MOTION	3*	5	5	4	7
MANEUVERS	2	4	1	2	3
NOISE	7	1	6	4	6
ODOR	1	2	1	1	3
TEMPERATURE	7	0	7	3	4
VENTILATION RATE	7	0	8	3	3
HUMIDITY	5	1	6	2	2
VIEW	0	4	0	0	5
MOVEMENT	1	3	1	1	6
SEAT WIDTH	4	2	6	0	4
LEG ROOM	5	1	6	0	4
SEAT CONTOUR	4	3	5	0	4
SEATING DENSITY	5	0	5	1	4
		TOTAL	57	21	55

*ENTRY INDICATES NUMBER OF RESPONDENTS CHOOSING THIS OPTION

Criteria sources for environmental factors for which criteria were judged inadequate were divided among the three categories as follows: Industry - 20 percent of responses; Government - 20 percent; and Experience - 60 percent. Sources of criteria judged adequate for establishing environmental requirements were broken down among these three categories as Industry - 51 percent; Government - 18 percent; and Experience - 31 percent. It appears that experience is used chiefly as a stop gap criterion in lieu of more definitive and quantitative criteria. More firmly established criteria are published in design handbooks, often under auspices of a professional engineering society.

Ranked importance of environmental factors to ride. Importance of each environmental factor to passenger ride acceptance is a further consideration in setting priorities for effort required to strengthen the ride technology data base. Of top priority would be an area in which existing criteria are judged weak and one with a large impact on passenger ride. Respondents were accordingly asked to rate each of 13 vehicle environmental factors along a five point rating scale in terms of judged importance to passenger acceptance of vehicle ride. A rating of "5" was assigned to factors considered "very important". Results are shown in terms of mean ratings in Table 9. Ratings were averaged over seven returns from persons involved in rail transportation and over six returns from persons involved in air transportation. Data from three returns, one in marine transportation and two in surface transportation (other than rail), were not analyzed because of the small number.

Noise and temperature were rated most important in terms of impact on passenger ride acceptance for both rail and air transportation. Ventilation rate and vibration were also seen as critical for both transportation modes. Persons involved in air transportation considered seating factors on the average to be more critical to passenger ride acceptance than did persons in the rail transportation mode, however. This difference persisted without reduction when each transportation mode was broken down into "short haul" and "long haul" components: concern with seating was not a function of differences in average trip duration for the two modes. Within mode, however, trip duration was weighted in determining impact of seating on passenger comfort. Persons involved in long haul transportation in both modes rated seating factors to be on the average 0.70 scale units higher than did persons involved in short haul transportation.

A possible reason for this difference between air and rail transportation is that air transportation is marketed along the lines of maintaining "living room" comfort during travel. Comfortable seating would be an important factor in maintaining this image, in meeting passenger expectancies of high personal comfort during travel. Seating would tend then to be rated highly in terms of its impact on passenger ride comfort.

Results shown previously in Table 8 indicated that design criteria in the areas of motion, maneuvers, view and provisions for onboard movement were judged largely inadequate. Of these, only motion was considered to be among the seven environmental factors judged most important in impacting passenger acceptance of ride. Results previously shown in Table 9 indicated that noise, temperature, ventilation rate, vibration and humidity were considered to be factors importantly affecting passenger ride acceptance. Existing criteria for all factors except vibration (motion) were judged to be adequate

TABLE 9
RELATIVE IMPORTANCE OF VEHICLE RIDE INFLUENCING FACTORS

DESCRIPTION	RAIL	AIR	SCALE VALUE
VERY IMPORTANT			5
	NOISE (4.86)* TEMPERATURE (4.57) VENTILATION, VIBRATION (4.29)	NOISE, TEMPERATURE (4.67) VENTILATION, SEAT WIDTH, LEG ROOM AND SEATING DENSITY (4.5) SEAT CONTOUR (4.43) VIBRATION (4.38)	
QUITE IMPORTANT			4
	HUMIDITY (3.86) LEG ROOM (3.57) SEATING DENSITY (3.43) ODOR (3.29) SEAT WIDTH, SEAT CONTOUR AND ENTRY/EXIT PROVISIONS (3.14)	HUMIDITY (3.67) ENTRY/EXIT PROVISIONS (3.62) MOVEMENT, SAFETY RESTRAINTS AND ODOR (3.5)	
MODERATELY IMPORTANT		VIEW (3.0)	3
	VIEW (2.57) MOVEMENT PROVISIONS (2.43)		
SLIGHTLY IMPORTANT			2
NOT IMPORTANT			1

*NUMBERS IN PARENTHESES ARE MEAN VALUES

in most cases, however. These results indicate that concern with effects of vibration on passenger ride comfort should take highest priority in future efforts to improve the ride technology data base. The question of the importance of interactions among environmental factors in affecting passenger comfort was not addressed directly in the questionnaire.

Needs for data base improvement - Respondents were asked to list areas in which significant improvements in the ride technology data base were needed. Results are shown in Table 10 in order of decreasing frequency of response. The seven needs for improvement cited at least twice all involved the vehicle motion environment, at least in part. Five of these seven were exclusively concerned with the motion environment. Needs for criteria improvement in areas not exclusively concerned with motion and which were cited at least twice concerned improved handling of interactions among environmental factors and improved criteria relating acceptable limits of both noise and vibration to ride segment.

Ride criteria formats - Of added concern in development of an adequate ride technology data base is that data be in a form readily translatable into meaningful guidelines or criteria. Respondents were asked, therefore, to list ride criteria formats currently being used for vehicle design and to indicate the formats most useful to them.

Responses to these questions again did not group themselves according to specific transportation modes. For this reason results summarized below do not regard differences in transportation modes.

Descriptions of ride criteria currently used primarily concerned vehicle vibration. This response is consistent with the interpretation of the term "ride quality" by many respondents. Eight of the 13 respondents to this question indicated some form of acceleration versus frequency plots were used. Other vibration criteria mentioned were, in order of descending frequency, peak exceedances (3), power spectral density curves (2), the "as good as" criteria (2), average acceleration (1) and duration limits (1). Numbers in parentheses following each criterion format are number of persons selecting that response. The number of formats in use exceeds the total number of respondents (13) to the question since some respondents indicated multiple criteria formats.

Acoustic criteria formats mentioned were dBA (2), non-specific acoustic format (2) and Speech Interference Level (1). Specified ranges of ambient air temperature, ventilation rate and humidity were mentioned twice. Evaluation of overall vehicle ride quality by company executives wes mentioned once.

Responses listing most useful formats for ride quality criteria fell into two categories: responses listing desirable general characteristics of ride criteria and those citing more specific criteria content. Desirable general characteristics were:

- that criteria be objective
    - objective, quantifiable (3)
    - formulas with weights for component terms (2)

TABLE 10
RIDE CRITERIA IMPROVEMENT NEEDS

NEED	NUMBER OF RESPONDENTS CITING NEED
ACCELERATION LIMITS ACCEPTABLE TO PASSENGERS	4
IMPACT OF EXTENDED RIDE DURATION	4
MULTIPLE-AXIS/MULTIPLE-FREQUENCY DATA	4
EFFECT OF MANEUVERS ON PASSENGER ACCEPTANCE	4
INTERACTIONS AMONG ENVIRONMENTAL VARIABLES	3
VIBRATION ACCEPTANCE CRITERIA IN PSD FORMAT	2
CRITERIA WHICH RELATE SOUND AND VIBRATION CRITERIA TO RIDE SEGMENT (TO ACCOUNT FOR VARYING PASSENGER EXPECTATIONS)	2
EFFECT OF SEAT ORIENTATION ON RIDE QUALITY	1
LOW FREQUENCY VIBRATION CRITERIA	1
NOISE CRITERIA	1
GENERAL RIDE QUALITY MODEL NEEDED (SPECIFIC FOR EACH TRANSPORTATION MODE)	1
STANDARDIZATION OF TEST PROCEDURES AND DATA	1
IMPROVED SPECIFICATION AND STANDARDS FOR TRACK IRREGULARITIES, GEOMETRY AND ROADBED COMPLIANCE	1
CRITERIA UNDERSTANDABLE AND USABLE BY NONTECHNICAL MANAGEMENT	1

- that criteria be simple and easily interpretible

  - interpretible by non-engineers (2)

  - consisting of simple quantitative or qualitative checks (2)

  - criteria should be in the form of a dimensionless number (1)

Numbers in parentheses following each statement indicate frequency of responses for each general statement.

Responses listing more specific most useful criteria formats were: RMS g acceleration versus frequency plots (3), RMS g acceleration versus frequency plots weighted for peak g incidents (2), and power spectral density plots (2).
"Do not exceed" limits and criteria relating environmental intensive changes to percentages of passengers satisfied were cited with equal frequency. Five respondents again indicated that criteria should be relevant for specific conditions; i.e., over specified sea states or tracks, for specified durations, and for specified transportation modes further broken down into travel segments when passenger expectation of ride quality can be expected to vary as a function of segments. The last point was cited for noise criteria as well as for vibration criteria. A criteria format to include better definition of peak wave distributions versus sea state and RMS g acceleration versus sea state was also mentioned as desirable.

Summary of questionnaire results. - General conclusions from the questionnaire survey are listed below. In brief, analysis of questionnaire returns disclosed the following users' views. Ride of commercial passenger vehicles is given considerable weight in marketing strategy for those vehicles, but is not the most or second-most heavily weighted design factor. Although vehicle noise, temperature, ventilation rate and humidity are important in determining passenger acceptance of the ride environment, existing criteria were judged adequate for specification of acceptable limits or ranges for these factors. Only vehicle motion (vibration or maneuvers) was listed both as an environmental feature for which existing criteria are inadequate and a heavily-weighted feature affecting passenger ride acceptance. Persons involved in air transportation tend to weight seating factors (leg room, seat width, seat contour and seating density) more heavily in influencing passenger ride acceptance than do those involved in rail transportation.

Most frequently used general sources of existing criteria are industrial standards and company/agency experience. However, heavy dependence on experience for setting vehicle ride quality criteria is viewed as undesirable. Independent, quantitative criteria are used preferably, but likely should be consistent with accepted experience. Most significant improvements to existing ride criteria would involve improving vibration/maneuvers criteria, although effects on passenger comfort from interactions of the key environmental factors should be studied. Ride criteria should be specific for cases in which they are relevant. Criteria should be specific for transportation modes for which passenger standards of an acceptable ride vary, for varying ride durations when duration affects ride comfort, and for different trip segments (such as takeoff, cruise, and descent for airplanes) for which passenger expectations of ride comfort vary. Ride criteria should be objective and easily interpretable by persons with non-technical

backgrounds. Better definition of the sea environment is needed for marine vehicles and better definition of track and track interactions with vehicle dynamics is needed for passenger rail vehicles.

Page
Intentionally
Left Blank

APPENDIX C

DETAILED RESULTS OF GROUP 2 WORKSHOP "NEEDS OF THE TRANSPORTATION COMMUNITY"

This workshop was conducted in conjunction with the NASA-DOT sponsored 1975 Ride Quality Symposium which is reported in NASA TM-X 3295.

Participants ranked vehicle ride along with other factors in terms of their impact on traveler acceptance and use of different transportation modes. The group concurred that ride ranked behind cost of travel and convenience of travel with the exception of marine vehicles. Passengers have been found willing to pay higher fares for rides in marine vehicles which significantly reduce the probability of motion sickness. It was assumed in this ranking that personal safety during the trip was assured so that this factor did not enter into the rank ordering.

Workshop participants also evaluated ride technology in terms of existing shortcomings of the existing data base applicable to all modes of commercial transportation and also specific to only one or a few modes. The shortcomings identified are presented in Table 11.

In addition, participants listed ride technology needs including needs for improvements in the data base and those of a more general nature. The five most important ride technology needs were identified in order of priority as: (1) improved guidelines and criteria, (2) better data defining interactions among factors, (3) improved data describing impact of nonmotion factors on passenger ride quality, (4) expansion of the motion data base, and (5) improved techniques for evaluating vehicle dynamics resulting from perturbing inputs and their transmission to the passenger.

Characteristics of criteria types. - The three basic types of ride criteria formats previously mentioned were evaluated and attributes and shortcomings of each type of criteria were then listed as shown in Table 12. Major shortcomings of the much-used AGA criteria discussed were that this form provides only limited information about acceptable intensities of environmental factors. No data are available by which to assess desirability of improving the environment over that of the comparison vehicle and no criterion exists for assessing degree of a ride problem if the AGA guideline is exceeded on some parameter. Hence cost/benefit trades are difficult. The AGA criterion can be useful only when there is sufficient similarity between the new and the comparison vehicle to warrant use of the comparison vehicle as a reference. This type criterion has uncertain application at best to new types of vehicles, i.e., those vehicles for which an existing vehicle of similar design cannot be found.

Evaluation of the Not-To-Exceed criteria was specific to the ISO Standard of Reference 20 so that listed shortcomings should be interpreted as defining needs for improvement in these standards. Unlike shortcomings listed for AGA criteria, no shortcoming listed for the ISO standard is inherent in the form of Not-To-Exceed criteria. The list of ISO standard shortcomings implies that there is a need to extend the criteria below 1.0 Hz, that criteria for angular degrees of freedom should be established and that more data are needed to confirm levels of acceleration limiting passenger comfort under varying exposure times. A family of not-to-exceed limits is desirable, perhaps associating percentage of passengers comfortable with varying acceleration levels. The family of curves would provide a basis for cost/benefit trades in vehicle design.

TABLE 11
RIDE TECHNOLOGY DATA BASE NEEDS

COMMON NEEDS
STANDARDIZED UNITS EXPANDED DATA BASE FOR DEFINING PASSENGER RESPONSE TO MOTIONS MORE DATA REGARDING INTERACTIONS AMONG MOTION DEGREES OF FREEDOM SEAT TRANSMISSIBILITY DATA

MODE SPECIFIC NEED	MODE								
	MARINE	URBAN RAIL	INTER-CITY RAIL	STOL AIR-CRAFT	CTOL AIR-CRAFT	HELI-COPTER	AUTO-MATIC GUIDE-WAY TRANSIT	TRANSIT BUS	INTER-CITY BUS
BETTER DEFINITION OF VEHICLE MOTION INPUTS	X	X	X						
EFFECTS OF NONMOTION FACTORS ON COMFORT		X	X	X		X	X	X	
EFFECTS OF VARYING TRIP DURATIONS	X		X		X	X			
EFFECTS OF VEHICLE ENVIRONMENT ON TASK PROFICIENCY								X	X
INTERACTIONS AMONG ENVIRONMENTAL FACTORS			X	X	X	X	X	X	X
EFFECTS OF MOTIONS ON STANDING PASSENGERS		X						X	X
BETTER LOW FREQUENCY VIBRATION DATA	X			X	X				
EFFECTS OF INPUTS ON OPERATOR COMFORT				X				X	X

TABLE 12
CRITERIA CHARACTERISTICS

CRITERIA TYPE	POSITIVE CHARACTERISTICS	NEGATIVE CHARACTERISTICS
AS GOOD AS (AGA)	RELATED TO KNOWN VEHICLES AND RESPONSE OF PASSENGERS TO RIDES OF THESE VEHICLES EASY TO SPECIFY COVERS ALL FACTORS OF ENVIRONMENT	COST/BENEFIT TRADES DIFFICULT DETERMINATION OF COMPLIANCE DIFFICULT UNCERTAIN APPLICATION TO NEW VEHICLE TYPES
NOT-TO-EXCEED (1974 ISO STANDARDS)	EASY TO SPECIFY VALUES COMFORT VS. ACCELERATION LEVELS AND FREQUENCIES CURVE NOT ARBITRARY EASY TO VERIFY COMPLIANCE	LIMITED TO $>$ 1.0 HERTZ APPLIES TO LINEAR DEGREES OF FREEDOM ONLY EXPOSURE TIME EFFECTS UNCONFIRMED ACCELERATION LEVELS OF CURVE ARBITRARY GO/NO-GO LIMIT ONLY
OUTPUT-TO-INPUT RELATIONSHIP	EASY TO SELECT VEHICLE SPECIFICATIONS EASY TO VERIFY COMPLIANCE	NEEDS WELL-DEFINED INPUTS TO VEHICLE

Consistent with this point, workshop participants judged that meaningful criteria should relate both the percentage of passengers satisfied over a given ride and the percentage of time passengers are satisfied with the ride. Data should be made available for support of cost/comfort trades. Criteria also should be sensitive to varying passenger expectations. For example, a passenger's concept of a comfortable or acceptable ride on a transit bus would likely vary from that same passenger's idea of an acceptable large aircraft ride at cruise altitude. Criteria applicable to each mode of transportation should reflect this difference.

General timetable - Finally, workshop participants established a general timetable for improvements in current ride technology. The timetable was based on general schedules for development of major transportation systems which would benefit from advances made in improving the technology. The schedule is presented in Table 13. It is clear from this listing that the workshop participants perceived the need for an immediate beginning of work to advance ride technology.

TABLE 13

APPARENT SCHEDULE REQUIREMENTS
FOR RIDE TECHNOLOGY IMPROVEMENTS

CONCEPT	TECHNOLOGY IMPROVEMENT NEEDED BY
ADVANCED PEOPLE MOVER	1975
ADVANCED TRANSIT BUS	1976+
LONG HAUL HELICOPTER	1976+
IMPROVED INTERCITY TRAIN	1978+
FUEL CONSERVATIVE CTOL	1977-1985
HIGH-SPEED INTERCITY BUS	1980+
POWERED LIFT STOL	1980-1985

Page
Intentionally
Left Blank

APPENDIX D

DETAILED INTEGRATED RIDE TECHNOLOGY DEVELOPMENT APPROACH

The proposed integrated ride technology development approach is discussed in detail in the following paragraphs. Reference is made to Figure 5 which is an expansion of the outline presented in Figure 4. Portions of Figure 5 corresponding to blocks of Figure 4 are set off by solid lines and appropriately labeled. Each of these sections will be discussed in detail in the following paragraphs.

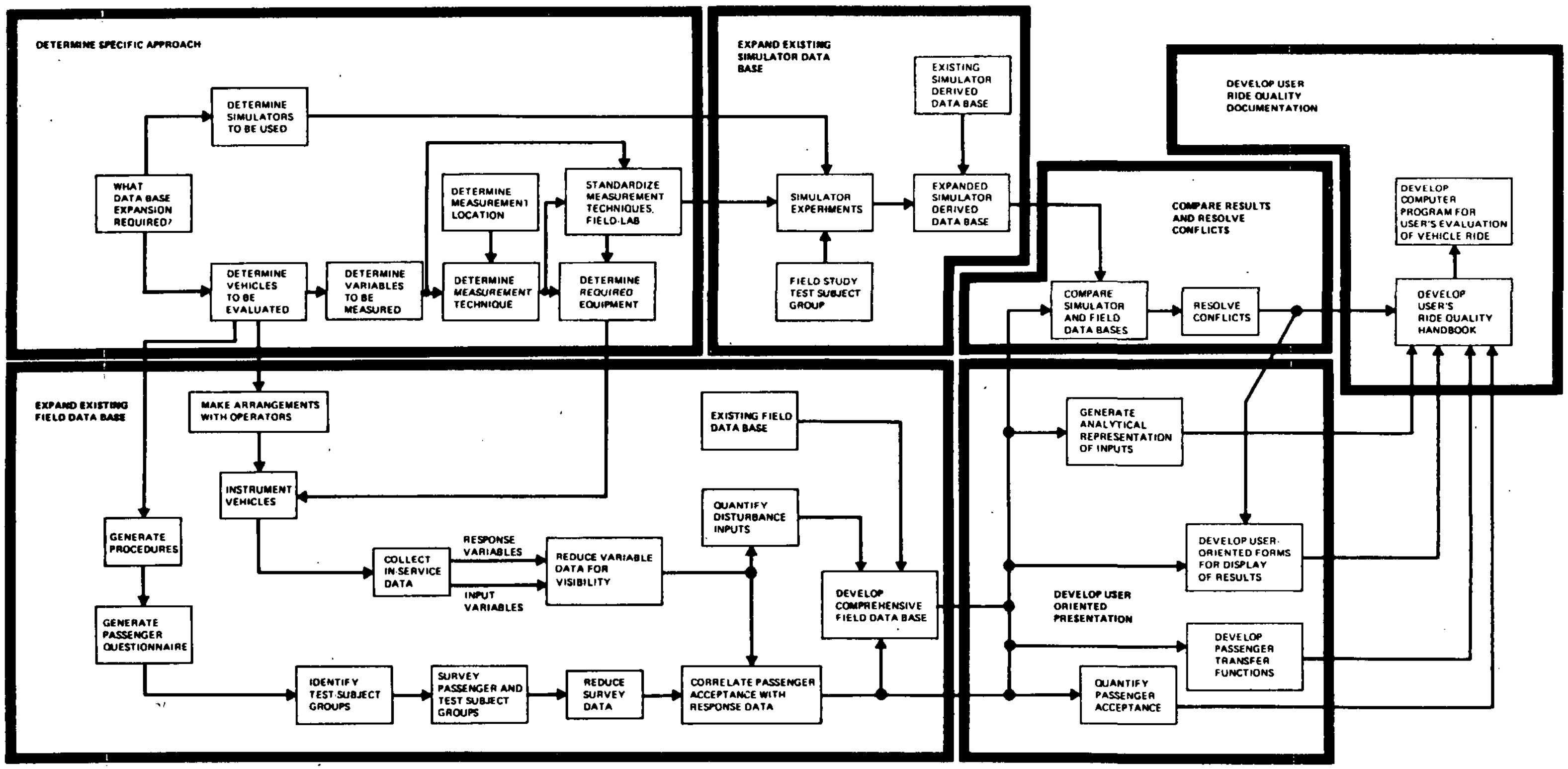
The specific approach: The first step in determining the specific approach to ride technology development is to identify the deficiencies in the existing ride technology data base. A preliminary examination of this area has been conducted in this study. However, this survey should be expanded so that the scope of the total undertaking may be understood. Once these deficiencies are sufficiently well defined, a plan can be developed to eliminate them most efficiently through the proper use of available facilities and expertise.

The choice of facilities to be utilized is basically between simulators and operational vehicles. Each approach has its merits. For instance, simulators are generally less expensive to operate and provide greater capability for experimental control but validity of simulator data is uncertain. Operational systems, while providing realistic results, pose problems for data retrieval and evaluation, especially for passenger subjective reaction.

The simulator or vehicle system to be used should be chosen for its unique ability to contribute in a specific area of need. When choosing a simulator, for instance, many classes are available. These range from the fixed base class through limited motion types to full motion vehicles available for operational evaluation. Simulators may, of course, vary in degree of sophistication in representing environmental factors other than motion.

In a like manner, operational vehicle systems employed to expand the technology data base must be carefully chosen to provide maximum usable data for minimum investment. Systems representative of those used for air, surface and marine mass transportation should be chosen with possible major subdivision within modes occurring where special emphasis is advisable. For instance, such subdivision might be required in the study of short haul and long haul aircraft or in the study of rail transportation which could be broken down into intra or inter-city applications. A similar subdivision of the marine transportation modes might be expedient, separating hull-borne from foil-borne vehicles.

Once the transportation systems and vehicles to be studied are determined, variables to be measured must be identified. These variables would include such candidates as linear and angular acceleration, angular rates, noise, temperature, humidity and others as necessary. In specifying variables to be measured it is also very important to specify the method of measurement and method of data reduction as pertinent. Specifications would include type of sensor, such as accelerometers, gyros, strain gauges, etc., and type of recording equipment if data reduction is not accomplished on board. Space and power requirements must



DETAILED DIAGRAM - INTEGRATED RIDE TECHNOLOGY DEVELOPMENT APPROACH
FIGURE 5

also be determined. In addition, the location of any measurements made should be specified according to the vehicle body station, the floor, seat, the sensitive axis orientation and whether or not dummies will be used. This is not an exhaustive list of decisions to be made but is typical. In making all these determinations it must be observed that comparisons between field and simulator data will ultimately be required so care must be exercised to preserve compatible formats.

The simulator data base: The majority of the ride technology data base has been developed from simulator studies. These studies have generally addressed only one ride factor at a time such as acceleration or noise and in the case of acceleration only one axis at a time. This work needs to be extended to include more complex and more realistic environments. For instance, multi-axis acceleration effects can be studied and this part of the data base expanded and compared with single axis effects. Also multiple frequency effects can be studied in interaction with effects of habitability variables such as temperature, humidity and ventilation. In addition, the effects of duration and of various seat designs can be studied effectively.

One area of possibly fruitful study would be in the development of a standard test subject group to use in both simulator and field studies. The University of Virginia reported in Reference 35 that good success was achieved in developing a test subject group which produced ride rating results consistent with the general passenger population encountered in short haul aircraft. Use of a standard test subject group such as this would enhance capability to correlate simulator results with field results. Good correlation in many areas would raise confidence in basic simulator results and would also eventually reduce required field testing.

The field data base: Having previously determined the type of vehicles to be included in the field tests, arrangements for cooperation with appropriate operators must be made. Required cooperation will vary for different operators and different transportation vehicles so that specific obligations must be worked out for each case. The primary area of concern may be the instrumentation of vehicles if carry-on instrumentation is not adequate. In any case, arrangements will be necessary for preferential seating if a standard rating test group is used.

As a part of this effort it will be necessary to generate data retrieval and processing procedures. This may include both instrumented data and passenger subjective reactions obtained through questionnaires. Appropriate questionnaires will have to be constructed to generate meaningful data and, again, the cooperation of the vehicle system operator will be necessary to approve questionnaire content and to distribute and retrieve the questionnaires. The experimental procedure will most probably include selection of a standard group of test subjects who will be responsible for any carry-on equipment and data collection. One of the primary functions of this group will be to provide the means to determine if adequate realism can be provided in simulators to produce passenger subjective reactions that are similar to those actually obtained in the field.

Data of two basic types should be collected during these tests. One type would be objective data based either on vehicle responses or on inputs to the vehicle actually measured and recorded. In addition, while vehicle response data are being collected, data defining the inputs being experienced should be

collected. This might be done by means of a gust probe for aircraft, wave height measurements for marine vehicles, or surface irregularity measurements for rail or surface vehicles. Availability of this information will improve math modeling capability for realistic inputs. The second type of data is passenger subjective ride response which will probably be collected through questionnaires.

Both types of data must be reduced and presented in the most usable format. For objective data this format might be root-mean-square values for a given input, a power spectral density plot, magnitude versus frequency plots, a count of number of exceedances, etc. The passenger questionnaire data might be presented on a rating scale or as percent of passengers satisfied.

Data generated from these field experiments in all transportation modes will be used to augment the existing ride technology data base. An attempt should then be made to determine various effects from these data to compare with similar simulator results. Some of the effects to be determined might be related to seats, duration of trip, transient inputs, multi-axis or multi-frequency inputs, and interaction effects of habitability variables such as temperature and humidity. Again this comparison of field and simulator data presupposes a common format for data derived from each source.

Comparison of results and resolution of conflicts: One of the more important facets of this effort would be the comparison of results from the simulator and field experiments. Conflicts in this area will naturally arise because of the inability of a simulator to accurately represent the environment of an actual transportation system. On the other hand, constraints in phrasing of questionnaire items and in control of the environment may limit interpretability of field data. The resolution of such conflicts will prove to be a fruitful area of research which will lead to a better understanding of the use of simulators and operational vehicles in developing ride quality technology. In particular, increased understanding of these conflicts should lead to an improved ability to predict passenger ride acceptance based on simulator results so that new designs can be adequately evaluated prior to prototype development.

User oriented presentation: Another important result of this effort would be the development of standardized user-oriented presentation formats for ride quality technology, data and criteria. This would greatly facilitate communication among users and between contracting parties, thus reducing the possibility of misunderstanding or of incorrect application of criteria.

One additional area that must be addressed in transportation modes other than air is the formulation of a proper model of normally encountered disturbing inputs. For rail transportation this would be the track; for rubber tired vehicles this input would be the guideway or roadbed; and for marine vehicles it would be the sea. Models of these disturbances could be generated in the same manner as has been accomplished for the atmosphere where power spectral density of magnitudes and probability of encounter of various size gusts have been well quantified. Availability of this information would complete the kit of tools that the designer would need to predict passenger satisfaction analytically, given the ride characteristics in any transportation mode for any specified disturbance input.

In the area of developing an analytical representation of the passenger

transfer function, pioneering work has been accomplished by the University of Virginia under a NASA grant, as described in Reference 36. A method was developed for evaluating ride by field experiments with public transportation vehicles. This method relates the vehicle operational environment and performance characteristics to determine the probability of satisfying the passenger. This approach may be used to study new designs as well as existing vehicles and might be considered as the model upon which future work could be based. At present, ride quality of only short haul aircraft has been addressed in this manner although the approach is being extended to intercity bus and rail in the northeast by Dunlap Associates with the assistance of the University of Virginia. The method is general and could easily be applied in detail to all modes of transportation. In addition, the method would allow prediction of passenger statisfaction for new vehicle designs before actual construction.

The general technique is described in References 35 and 37, in which a model of passenger comfort and satisfaction based on vehicle motion is described. This technique was developed as a part of a larger effort to assess passenger satisfaction with transportation systems. The total effect of all type inputs was not addressed since assessment of complex interactions would be overly difficult for initial study. Motion was considered the most important vehicle factor influencing ride quality. At present, the technique reflects comfort and satisfaction only as a function of vehicle motion, although recent results have included the relationship of noise to motion in determining passenger acceptance as shown in Reference 38. Effects of other variables such as temperature, humidity, pressure changes and seat geometry should be addressed in the future.

It is important to note that both quantitative data and subjective evaluations were obtained primarily during normal commercial operation of the transportation mode being investigated, although some supporting work was accomplished using a flight simulator aircraft as reported in References 39 and 40. Subjective evaluations were obtained in questionnaires and were derived from special test subjects as well as commercial passengers. A detailed analysis of the questionnaires which solicited more than just response to motion is presented in Reference 35.

Various models of passenger comfort were investigated during this series of studies and a preferred model was proposed. The model chosen is linear, uses only vertical and lateral rms accelerations as inputs, and provides a description of passenger comfort which is adequate for the proposed use. With this model one can predict the comfort level of a passenger on a short haul aircraft with a reasonable degree of accuracy based only on the rms values of vertical and lateral acceleration. For this particular transportation mode it was determined that the effects of other variables were small.

The final step is to obtain relative passenger satisfaction with ride as it relates to comfort (either predicted or real). Work also conducted by the University of Virginia has led to the development of a model of percent of passengers satisfied with respect to comfort rating. This result was reported in Reference 12.

With all these tools at hand, one may then predict a typical passenger's reaction to motion, or comfort, in a transportation mode and then predict the percent of passengers that would be comfortable in that environment.

This method of quantifying passenger ride satisfaction appears to be compatible with any transportation mode. It remains to be determined, however, exactly how a different transportation mode would modify characteristics of these data. For instance, it might be expected that isocontours of passenger comfort curves would change or that the weighting of rms acceleration in the comfort model might change depending on the transportation mode. It is quite conceivable that in other transportation modes motion variables other than linear acceleration might become dominant. These problems would have to be worked out as encountered but the basic concept appears workable.

User Ride Quality Documentation: The ultimate result of this integrated ride quality technology development effort should be a working document or handbook for persons involved with specification, procurement, operation or design of transportation systems and vehicles. This handbook should contain information pertinent to the specification and/or analysis of transportation vehicle ride quality or passenger satisfaction with ride.

Availability of such a handbook should eliminate many of the user needs that have been exposed during this study. For instance, in the area of standardization, this handbook would facilitate communication between contracting parties, encourage more adequate application of criteria and provide a firm base for determining requirements for demonstrating specification compliance. Improved communication resulting from standardization and availability of source data from the handbook should result in improved application of analytical techniques and increased confidence in results.

The availability of adequate passenger models and quantification of subject reaction will allow the system designer to predict passenger satisfaction and to manipulate design factors to reduce system cost as a function of ride quality provided. Also, adequate analytical representation of disturbance inputs will allow evaluation of effects on ride of both existing and advanced guideways of innovative construction.

A further refinement of the Users' Ride Technology Handbook could be a computer program with which to analyze the ride quality and passenger acceptance of a new vehicle. This computer program would provide a standard method for handling data, characterizing inputs and defining models. Another portion of such a program (or a separate program) could provide a standardized method of data reduction from field tests of actual vehicles. This concept would remove some of the variability now existing in all phases of ride quality research and application.

It is reasonable to assume that the designer's handbook should be revised over time to reflect new developments in the ride technology data base. Procedures for such revisions should be established.

REFERENCES

1. McKenzie, J. R.; and Brumaghim, S. H.: Review of Ride Quality Technology Needs of Industry and User Groups. 1975 Ride Quality Symposium, Paper No. 1, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

2. McKenzie, J. R.; and Brumaghim, S. H.: Ride Quality User Needs: A Review and Proposed Action. Presented during Session 112 of the Transportation Research Board 55th Annual Meeting, Washington, DC, January 1976.

3. Holloway, R. B.; and Brumaghim, S. H.: Tests and Analyses Applicable to Passenger Ride Quality of Large Transport Aircraft. NASA TM X-2620, Symposium on Vehicle Ride Quality, October 1972.

4. Grether, W. F.; Harris, C. S.; Ohlbaum, M.; Sampson, P. A.; and Guignard, J. C.: Further Study of Combined Heat, Noise and Vibration Stress. Aerospace Medicine, Vol. 43, No. 6, June 1972, pp. 641-645.

5. Shaw, L. M.; and Little, G. F.: Transbus Ride Characteristics: An Objective Test Methodology. Paper presented at the Intersociety Conference on Transportation sponsored by the American Society of Mechanical Engineers, Denver, Colorado, September 24-27, 1973.

6. Brock, B. J.: Determination of Guideway Roughness from Construction Tolerances. The Shock and Vibration Bulletin, Bulletin 44, Part 2 of 5 Parts, August 1974.

7. Healey, A. J.; Stearman, R. O.; and Smith, C. C.: Automobile Riding Quality with Real Highway Roughness. AIAA Paper No. 74-1301, AIAA Life Sciences and Systems Conference, November 1974.

8. Jacobson, I. D.: Environmental Criteria for Human Comfort - A Study of the Related Literature. NASA CR-138144, University of Virginia, February 1974.

9. Anon.: 1975 Ride Quality Symposium. NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

10. Conner, D. William: Nonmotion Factors Which Can Influence Ride Quality. Paper No. 5, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

11. Snyder, W. J.; and Schlegel, R. G.: Vehicle for Civil Helicopter Ride Quality Research. Paper No. 6, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

12. Richards, L. G.; Kuhlthau, A.R.; and Jacobson, I. D.: Passenger Ride Quality Determined from Commercial Airline Flights. Paper No. 18, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

13. ASHRAE Handbook of Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1972.

14. Life Support Systems Requirements. Vol. II, Section II, Biotechnology Requirements. ASD-TR-70-47, November 1970.

15. Bioastronautics Data Book Final Report. September 1972. (AD 749 887)

16. Personnel Subsystems, AFSC Handbook DH1-3, Series 1-0, General.

17. Schlegel, R. G.; Stave, A. M.; and Wolf, A. A.: Ride Quality Criteria for Large Commercial Helicopters. NASA TM-X-2620, October 1972.

18. Guignard, J. C.; and Guignard, Elsa: Human Response to Vibration - A Critical Survey of Published Work. ISVR Memorandum 373, Institute of Sound and Vibration Research, University of Southampton, 1970.

19. Griffin, M. J.: A Review of Ride Comfort Studies in the United Kingdom. Paper No. 20, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

20. International Organization for Standardization (ISO), Guide for the Evaluation of Human Exposure to Whole Body Vibration. International Standard ISO/DB 2031, 1974.

21. Allen, Geoff R.: Ride Quality and International Standard ISO 2631 (Guide for the Evaluation of Human Exposure to Whole-Body Vibration.) Paper No. 21, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

22. Janeway, R. N.: Analysis of Proposed Criteria for Human Response to Vibration. Paper No. 22, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

23. von Gierke, H. E.: The ISO Standard: Guide for the Evaluation of Human Exposure to Whole-Body Vibration. Paper No. 23, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

24. Jacobson, I. D.; Kuhlthau, A. R.; and Richards, L. G.: Application of Ride Quality Technology to Predict Ride Satisfaction for Commuter-Type Aircraft. Paper No. 3, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

25. Kirby, R. H.; Coates, G. D.; Mikulka, P. J.; Dempsey, T. K.; and Leatherwood, J. D.: Effect of Vibration in Combined Axes on Subjective Evaluation of Ride Quality. Paper No. 15, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

26. Wolf, T. D.; Rezek, T. W.; and Gee, S. W.: Passenger Ride Quality Response to an Airborne Simulator Environment. Paper No. 16, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

27. Dempsey, T. K.; and Leatherwood, J. D.: Vibration Simulator Studies for the Development of Passenger Ride Comfort Criteria. Paper No. 25, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

28. Schoonover, W. Elliott, Jr.: Ride Quality of Terminal-Area Flight Maneuvers. Paper No. 17, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

29. Stone, R. W. Jr.: Simulator Studies and Psychophysical Ride Comfort Models. Paper No. 26, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

30. Jacobson, I. D,; and Kuhlthau, A. R.: Flight Research Experiments to Determine Ride Quality and Passenger Acceptance. Memorandum Report 403903, University of Virginia, July 1974. (NASA CR-139738)

31. O'Hanlon, J. F.; and McCauley, M. E.: Motion Sickness Incidence as a Function of the Frequency and Acceleration of Vertical Sinusoidal Motion. Technical Report 1733-1, Human Factors Research, Inc., Goleta, Calif., September 1973.

32. Malone, W. L.; and Vickery, J. M.: An Approach to High Speed Ship Ride Quality Simulation. Paper No. 10, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

33. Shoenberger, R. W. : Subjective Response to Very Low-Frequency Vibration. Aviation, Space and Environmental Medicine, Vol. 46, No. 4, June 1975, pp. 785-790.

34. Ravera, R. J.: Ride Quality Criteria and the Design Process. Paper No. 2, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

35. Richards, L. G.; Jacobson, I. D.: Ride Quality Evaluation I: Questionnaire Studies of Airline Passenger Comfort. Ergonomics, 1975, Vol. 18, No. 2, pp 129-150.

36. Jacobson, I. D.; Kuhlthau, A. R.; and Richards, L. G.: Application of Ride Quality Technology to Predict Ride Satisfaction for Commuter-Type Aircraft. Paper No. 3, NASA TMX-3295, DOT-TSC-OST-75-40, 1975.

37. Jacobson, I. D.; and Richards, L. G.: Ride Quality Evaluation II: Modeling of Airline Passenger Comfort. Memorandum Report 403217, University of Virginia, December 1974.

38. Jacobson, I. D.; Rudrapatna, A. M.; amd Kuhlthau, A. R.: Interior Aircraft Cabin Noise - A Field Study. Presented at the 3rd Interagency Symposium on University Research in Transportation Noise, Snowbird, Utah, November 12-14, 1975.

39. Jacobson, I. D.; Schoultz, M. B.; and Blake, J. C.: Effect of Motion Frequency Spectrum on Subjective Comfort Response. Memorandum Report 403901, University of Virginia, November 1973 (NASA CR 138883).

40. Jacobson, I. D.; and Kuhlthau, A. R.: Flight Research Experiments to Determine Ride Quality and Passenger Acceptance. Memorandum Report 403903, University of Virginia, July 1974.

NASA-Langley, 1976

Page
Intentionally
Left Blank

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546